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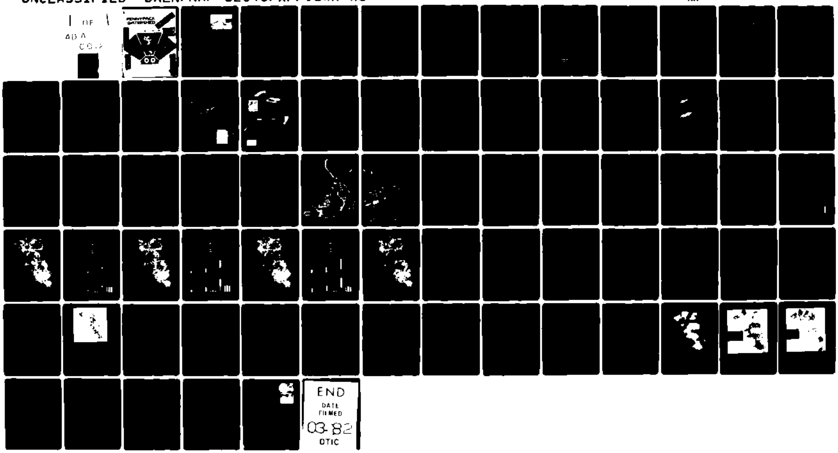

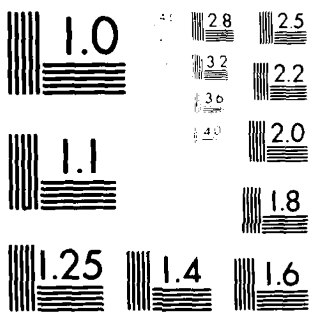

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Expanded Flood Plain Information

PENNYPACK WATERSHED

Pennsylvania

TECHNICAL REPORT

FLOOD HAZARD IDENTIFICATION
FLOOD DAMAGE ASSESSMENT
ENVIRONMENTAL CONCERNS

September 1980

U.S. Army Corps of Engineers • Philadelphia District

PREFACE

Federal programs such as the Corps of Engineers' Flood Plain Management Services Program and the Federal Insurance Administration's Flood Insurance Study Program have provided important basic information about flood hazards to communities, based on existing watershed development. However, there is urgent need for more comprehensive studies that can also predict the hydrologic, hydraulic, economic and environmental impacts of future development and regulatory policies on watersheds within communities.

Recognizing that these studies could be valuable tools to help local planning agencies in comprehensive planning and floodplain management, the Corps of Engineers embarked on a pilot study program, and selected the Pennypack Watershed as one of 10 pilot study areas nationwide. This pilot study program developed and applied methodologies that can effectively model existing watershed conditions, and can identify the impact on floodplain areas of future development both on and off the plain. This pilot program included the development of Expanded Flood Plain Information (XFPI) Studies, which provide more dynamic and comprehensive watershed analyses than previously available.

The Pennypack Watershed XFPI Study was initiated by requests from the Philadelphia City Planning Commission, the Montgomery County Planning commission and the Pennypack Watershed Association. The goals of the study were to develop a dynamic mathematical model of the watershed to provide basic information on flood hazards, flood damages and environmental impacts for existing and future development, including floodplain management policies. The intent was to give local agencies a dynamic and comprehensive planning tool for making sound decisions to deal effectively with flooding and its related problems in thr ?ennypack Watershed.

The Pennypack Watershed XFPI Study was conducted by the Philadelphia District, U.S. Army Corps of Engineers under basic authority in Section 206 of the 1960 Flood Control Act, as amended. The

Scene from Pennypack Park, Philadelphia.

Philadelphia District gratefully acknowledges the assistance and cooperation of the U.S. Army Corps of Engineers Hydrologic Engineering Center, the Pennypack Watershed Association, the Montgomery County Planning Commission, the Philadelphia City Planning Commission and the Townships of Upper Southampton and Warminster, Pa. in the conduct of this study. Upon request, the Philadelphia District will provide technical assistance to planning agencies in the interpretation and use of the data presented here. The mathematical model and data bank from this study are available for future analyses and technical services.

For more information, please contact:

U.S. Army Engineer District, Philadelphia
Custom House
2nd and Chestnut Streets
Philadelphia, PA 19106
Attention: Flood Plain Management Services Branch, NAPEN-M
Phone: (215) 597-4807

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
DAEN/NAP-82040/XFPI30r-80/09

2. GOVT ACCESSION NO.
AD-A110 012

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
Pennypack watershed, Pennsylvania: expanded flood plain information ~~technical report~~

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER
DAEN/NAP-82040/XFPI30r-80/09

7. AUTHOR(s)

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Army Engineer District Philadelphia
2nd & Chestnut Sts.
Philadelphia, PA 19106

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

12. REPORT DATE
Sept. 1980

13. NUMBER OF PAGES
65

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Floods	Pennypack Creek, Pa
Flood Control	Flood damage
Land use	Flood plain

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this technical report on the Pennypack watershed XFPI pilot study is to give local planning officials and agencies the results of a comprehensive investigation of the implications of future land use changes in the watershed. This report documents data and technical procedures. It also details results and conclusions from the investigation of flood hazard, flood damage and environmental impact potential of possible changes in land use both on and off the floodplain.

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Flood flows and flooded areas were found to increase slightly for the Pennypack Watershed as a whole. However, floodflows in individual sub-basin areas were found to increase by as much as 20% for a 100 year flood and up to 36% for a 10 year flood. In general, as the watershed continues to develop, floodflows (and also flood depths and flooded areas) can be expected to increase more for frequent flood events than for infrequent events. Local flood hazard impacts vary widely because of variations in development densities, ground cover and topography.

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Expanded Flood Plain Information Study

PENNYPACK WATERSHED

Pennsylvania

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REPT. NO: DAEN/NAP-82040/XFPI3R-80/09

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EXECUTIVE SUMMARY

The purpose of this Technical Report on the Pennypack Watershed XFPI Pilot Study is to give local planning officials and agencies the results of a comprehensive investigation of the implications of future land use changes in the watershed. This report documents data and technical procedures. It also details results and conclusions from the investigations of flood hazard, flood damage and environmental impact potential of possible changes in land use both on and off the floodplain. A shorter Summary Report of this study has been prepared for broader distribution.

Methodology

Two new, state-of-the-art computer techniques were basic to the study:

- A digital (grid cell) data bank of watershed characteristics
- A system of programs that automatically accesses the data bank, performs computations and analyses, and prepares tabular, graphical and mapped results

These computer techniques allowed dynamic and systematic analyses under all conditions and alternatives. The data bank is easily updatable, and remains available for supplemental investigation or future studies.

Technical Evaluations

Study results have been quantified for three major areas of concern in comprehensive land use planning:

- Flood Hazard Potential: flood flows; flood depths/flooded areas
- Flood Damage Potential: single event (e.g. 100-year flood) damages; average annual damages
- Potential Environmental Impacts: general environmental and habitat assessment; general water quality assessment; resource information and analysis

Alternative Future Land Use Conditions

Relative impacts of changing land use were evaluated for the base condition of Existing (1977) Land Use, and for three Alternative Future Land Use

TABLE 1

SUMMARY OF STUDY RESULTS

	Existing Development	Alternative A	Alternative B	Alternative C
Land Use	• 64% urbanized (47% residential) • 36% undeveloped	• 70% urbanized (51% residential) • 30% undeveloped	• 82% urbanized (61% residential) • 18% undeveloped	• 88% urbanized (65% residential) • 12% undeveloped
100-Year Flood Flow/Area	• 14,300 cubic feet/sec.	• 1% increase in flow	• 4% increase in flow	• 7% increase in flow
	1868 acres flooded	• 1% increase in acres flooded	• 2.6% increase in acres flooded	• 3.3% increase in acres flooded
100-Year Flood Damage	• $23 million	• 1.3 times greater	• 2.4 times greater	• 3.9 times greater
Average Annual Flood Damage	• $2.3 million	• 2 times greater	• 4.5 times greater	• 10 times greater
Environmental Assessment	• Many valuable acres already lost; water quality is typical of a predominately urbanized watershed	• 15% of undeveloped areas lost; expected decline in water quality	• 50% of undeveloped areas lost; expected decline in water quality	• 67% of undeveloped areas lost; expected decline in water quality

Plans identified by key watershed representatives of the Montgomery County Planning Commission, the City of Philadelphia Planning Commission, the Bucks County Townships of Southampton and Warminster and the Pennypack Watershed Association:

Alternative A: Continued development with general environmental constraints on steep slopes, prime open space and flood plain areas.

Alternative B: Continued development following existing patterns, but without constraints.

Alternative C: Continued development in accordance with existing land use zoning.

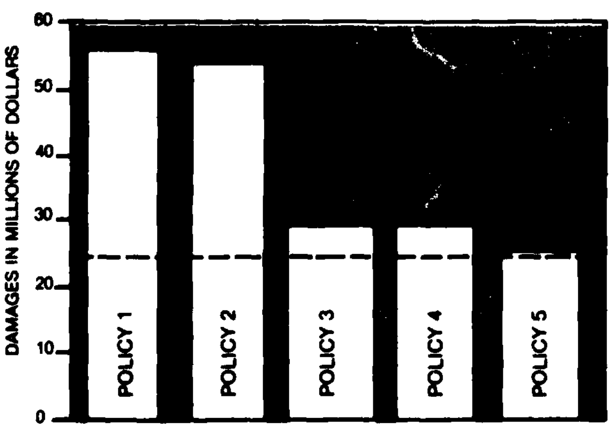
Study Results

Existing and Alternative Future Land Use Plans, without specific floodplain regulation, were analyzed for their flood hazard, flood damage, and general environmental impacts:

In general, the flood hazard impacts of the Alternative Future Land Use Plans were found to be moderate as compared to existing conditions. Flood flows and flooded areas were found to increase slightly for the Pennypack Watershed as a whole (as shown in Table 1). However, floodflows in individual sub-basin areas were found to increase by as much as 20% for a 100-year flood, and up to 36% for a 10-year flood. In general, as the watershed continues to develop, floodflows (and also flood depths and flooded areas) can be expected to increase more for frequent flood events (e.g. 10-year flood) than for the more infrequent events (100-year and 500-year floods). Local flood hazard impacts vary widely because of variations in development densities, ground cover and topography.

TABLE 2

100-YEAR FLOOD DAMAGE POTENTIAL LAND USE PLAN - ALTERNATIVE B



With unregulated future development the potential of increasing flood damages was found to be significantly greater than increases in runoff. For example, in the absence of flood plain regulation, full development of the watershed according to the Alternative B Land Use Plan (82% urbanized) could quadruple average annual flood damages vs. a 2.6% increase in flooded area for the 100 year event.

Regulatory Policies

In addition to assessment of alternative future land use plans (representing varying types and densities of land use), five Flood Plain Management Regulatory Policies were also considered for their effectiveness in mitigating flood damage potential:

- Policy 1 — No constraints
- Policy 2 — Runoff maintained at existing (1977) levels
- Policy 3 — Floodway restrictions (similar to those of the National Flood Insurance Program)
- Policy 4 — Floodway restrictions with flood-proofing (closure of openings)
- Policy 5 — Floodway/floodproofing requirements with runoff restrictions (Combination of Policy 2 and 4)

Positive effects of active flood plain management policies were found, as shown in Table 2 below, "100-Year Flood Damage Potential," which presents a good example of the effects of regulatory policies on the Alternative B Land Use Plan.

Environmental Assessments showed that up to two-thirds of existing plant/animal habitat areas could be lost under full development of the watershed, with a general (though moderate) decline in water quality, which is already causing local concern.

Fully detailed results of all analyses of Alternative Future Land Use Plans and Regulatory Policies are presented in the main body of this report.

Review

As we have seen, the impacts of alternative land use plans and policies can be predicted by computer modeling. Due to inevitable development, the potential for increased flood hazards, flood damages, and undesirable environmental impacts is great unless informed land use planning and effective floodplain management are implemented and maintained. The most effective techniques for reducing these potential impacts are to:

- Site future development out of flood-prone areas (implementation of Policy 3)
- Reduce the potential for increased runoff from the watershed (implementation of Policy 2) as development increases off the flood plain
- Require new construction in potentially hazardous areas to be "flood proofed" as far as possible (implementation of Policy 4)
- Uniformly applying strict enforcement of all applicable present requirements by all local authorities in floodplain areas

Local governments and agencies must continue to meet these planning goals by:

- Floodplain regulations and ordinances
- Residential subdivision regulations
- Commercial, industrial and residential building codes

Alternative A, Future Land Use, and Policy 3, floodway restrictions, have the best overall potential for reducing future flood hazards, flood damage and environmental impacts. Adding floodproofing and runoff restrictions (Policies 4 and 5) to Alternative A provides further, but not as significant, reductions.

Local impacts and impacts for the more frequent flood events may vary widely. Detailed results and analyses are presented in the body of this Report.

With foresighted planning and action anticipated flood damage can be held at, or in some cases slightly below, its present level and undesirable environmental impacts can be minimized. As the watershed continues to develop, informed decisions must be made and effective actions taken. It is hoped that this study will help form the basis for both.

Other Study Products and Capabilities

Orthophoto (controlled aerial photo) base mapping at 1:4800 (1" = 400') scale, with 4' contour interval topographic overlays is available as a valuable byproduct of the study for future planning purposes.

Further Analyses: Scenarios of possible future land use and alternative policies analyzed and presented *in this study were chosen as the most meaningful for* future planning purposes, based on current trends in the Watershed. However, the possibility of other alternative land use plans and policies emerging over time was recognized at the outset of this study, and planned for by the creation of the computerized (grid cell) data bank. The data bank remains available for future analyses, of the type presented in this report, for other land use management plans that local agencies and governments might wish to consider.

Because the computer modeling reflects "sensitivity to change," which varies throughout the watershed, the practicality of updating the data bank and performing new computer analyses should be examined on a case-by-case basis.

Proposals for future analyses should be coordinated through the respective County Planning Commission or the Pennypack Watershed Association.

In addition, the grid cell data bank represents a wealth of watershed data that can be accessed, reviewed and mapped for a variety of planning purposes. Special computer programs are available that can search the data bank for the coincidence of desired watershed characteristics, calculate attractiveness "scores," and provide distance determinations to or from physical attributes of the watershed that may be important for general land use planning.

Other technical background data gathered or developed during the course of the study can be made available as needed. For further information or technical assistance, contact U.S. Army Engineer *District, Philadelphia.*

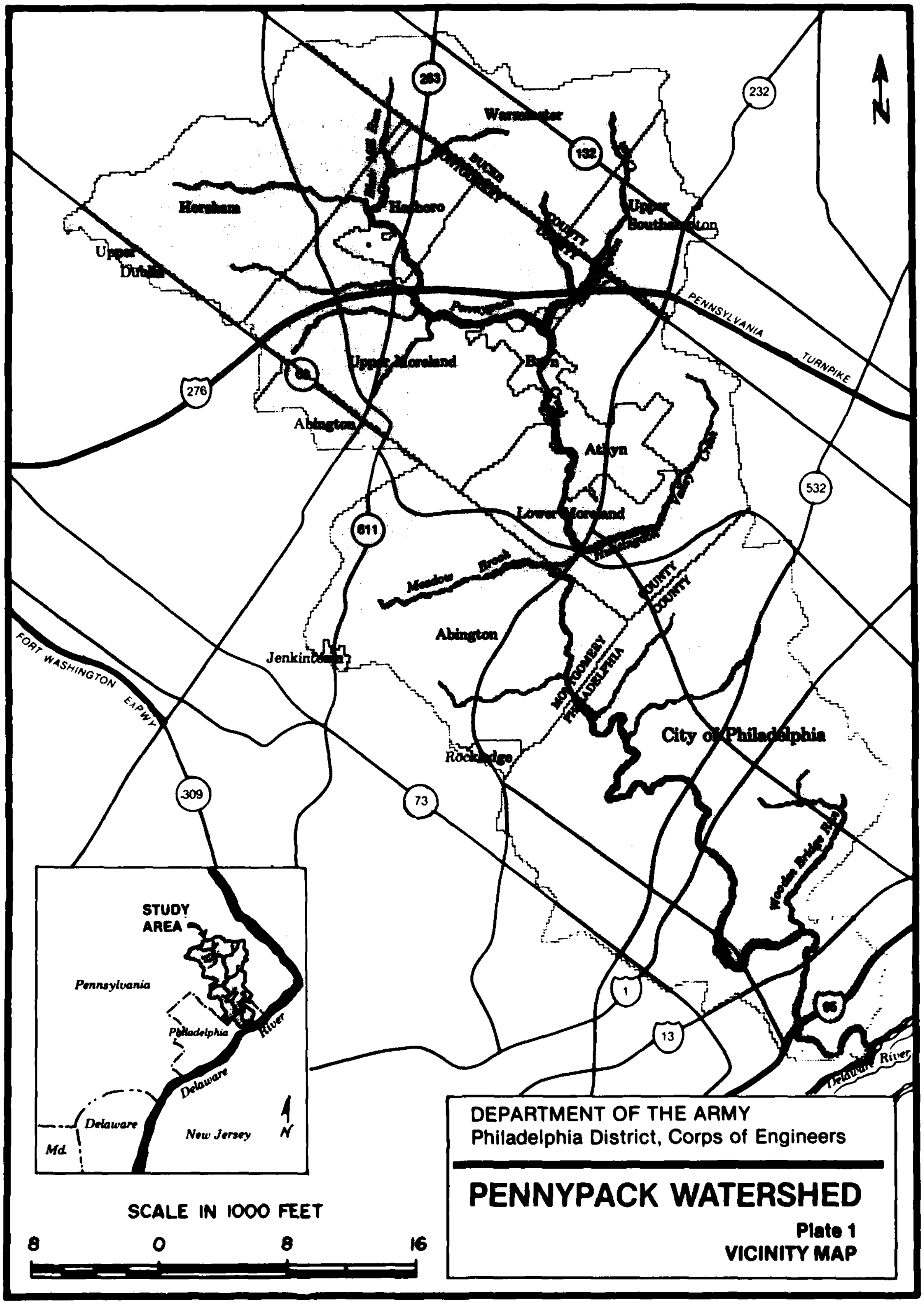
INTRODUCTION

To achieve overall study goals, innovative data management and analysis techniques were used. The study required efficient methods to handle large volumes of diversified data and to generate systematic, consistent analyses of all alternatives. The incorporation of computerized spatial analysis techniques within the overall study framework met these requirements.

These techniques included the development of a digital data bank of watershed characteristics and an automated system of computer programs for detailed analyses, and display of results. A grid was used to sub-divide the watershed, with each cell in the grid assigned a series of values for physical characteristics such as location, land use, soil type, elevation and slope. These geographic grid cells collectively represent the entire watershed, and can be accessed individually or in select groups for analysis or information. The methodology used, as far as practicable, proven techniques for conducting basic hydrologic, hydraulic, economic and environmental analyses. Modification and linkage of existing computer programs provided an automated system that could identify cause-effect relationships between various kinds of land use and floodplain management policies, and resultant storm runoff, flood stages, flood damages and environmental impacts.

The Philadelphia District incorporated into this study a system of spatial analysis techniques developed and compiled by the Corps of Engineers' Hydrologic Engineering Center (HEC), Davis, California.[1] This system includes computer programs for hydrologic and hydraulic analyses that the Corps of Engineers has used in many other water resource studies. The system also includes new computer programs and techniques developed or modified exclusively for the XFPI Pilot Study Program. Philadelphia District personnel tailored construction of the digital data bank to the character of the Pennypack Watershed, and developed additional computer programming and supplementary techniques for data acquisition and data bank creation and display.

Because relatively new, state-of-the-art computer technology was essential to the conduct of this study, the important study phases of data bank creation and execution of major computer programs have been documented in some detail in this report. It is hoped that this documentation will make the assessment of study results more meaningful and also make the data bank and available computer programming more useful to the future needs of planning agencies and others in the watershed.


Horsham
Upper Dublin
Upper Moreland
Abington
Lower Moreland
Jenkintown
Rockledge
City of Philadelphia
Meadow Brook
PENNSYLVANIA TURNPIKE
FORT WASHINGTON EXPWY
Delaware River
232
132
276
611
532
309
73
1
13
95
STUDY AREA
Pennsylvania
Philadelphia
Delaware
River
New Jersey
Md.
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16
DEPARTMENT OF THE ARMY
Philadelphia District, Corps of Engineers
PENNYPACK WATERSHED
Plate 1
VICINITY MAP

STUDY AREA

The Pennypack Watershed (Plate 1) is in the lower Delaware River Basin in Pennsylvania, and extends from suburban Bucks and Montgomery Counties to the confluence of the Pennypack Creek with the Delaware River in the City of Philadelphia. It drains an area of approximately 56 square miles and includes the main stem Pennypack Creek, the major tributaries of Blair Mill Run, Southampton Creek, Huntingdon Valley Creek, Meadow Brook and Wooden Bridge Run, and numerous smaller tributaries. Pennypack Watershed includes portions of the City of Philadelphia, the Boroughs of Bryn Athyn, Hatboro and Rockledge, and the Townships of Abington, Horsham, Jenkintown, Lower Moreland, Upper Dublin, Upper Moreland, Upper Southampton and Warminster.

Irregular in shape, the Pennypack Watershed is widest at the headwaters, measuring approximately seven miles across, and gradually narrows as Pennypack Creek flows toward its confluence with the Delaware River. Approximately 22 miles long, Pennypack Creek flows from elevations of approximately 390 feet, NGVD (National Geodetic Vertical Datum), at its headwaters to less than 10 feet, NGVD, at the Delaware River. Average streambed slope for the total length of the creek is 17.3 feet per mile. Starting with a slope of approximately 58.0 feet per mile at its headwaters, the gradient gradually decreases to only four feet per mile as the stream passes from the gently rolling topography of the headwaters, through a moderately sloping valley, and out onto the tidal flats preceding its confluence with the Delaware River. Overhanging trees and brush line the Pennypack's banks for most of its length.

As part of a major metropolitan area in the heavily developed northeast "corridor" from Boston to Washington, the Pennypack Watershed experiences significant developmental pressures from declining available land and rapidly escalating land values.

Development of the floodplain of Pennypack Creek has been kept to a minimum in Upper and Lower Moreland Townships, the Borough of Bryn Athyn and the City of Philadelphia due to the efforts of these communities and private landowners to preserve the floodplain for use as parkland and natural open space. The remainder of the floodplain along the main stem is characterized by heavy residential and commercial development, while its tributaries are experiencing an even more rapid increase in residential, commercial and industrial uses. Sewage treatment plants, utility lines, rail lines and highways are also located in the floodplain, subject to flooding by the Pennypack Creek and its tributaries. Although many sections of the watershed outside the floodplain contain residential and commercial development, there are still numerous undeveloped areas that are suitable for expansion.

STUDY PROCEDURES

General Methodology

This pilot study required the development of a modeling system for the Pennypack Watershed that could identify the flood flow, flood stage, flood damage and environmental implications of future development. This, in turn, required a more systematic and comprehensive study methodology than previous, more traditional floodplain delineation studies.

The basic types of desired information required input from several disciplines. This requirement was met by the formation of an interdisciplinary study team of hydrologic and hydraulic engineers, economists, environmental and floodplain management specialists and automatic data processing personnel. Each team member viewed the overall goals of the study from his own area of expertise; collectively the team guided the study effort through the key phases of problem identification, data collection, data bank creation, computer modeling and analysis of results. This coordinated interdisciplinary approach was necessary to reach meaningful conclusions about the cause-effect relationships among alternative developmental plans and policies and their effect on flood hazards and floodplain areas.

In addition to providing basic information on flood hazards, flood damage potential and environmental considerations for existing (1977) conditions, the study was to provide the same basic type of information for alternative future land use conditions and alternative assumptions of developmental policies. The modeling system was also designed to be easily updated and modified in order to accommodate changing watershed conditions and analyze other alternative developmental plans and policies that might be identified. These objectives required a methodology that could manage large quantities of varying types of data for existing and future conditions, and perform systematic and consistent analyses among alternatives.

These technical objectives were met by the HEC's system of spatial data management and analysis techniques, as the foundation of the study methodology. This automated system permitted efficient handling of large volumes of data and rapid analysis of alternative conditions. The computerized basis of the technique ensured that consistent and systematic analyses were made. Although computerized spatial data management and analysis techniques are still very much at the leading edge of technology, their use was essential to the success of this pilot study.

Spatial Data Management and Analysis Techniques

The system is comprised of a computerized data bank and a series of data management and analysis computer programs. Spatial data management techniques were used to develop resource data files. Special-purpose computer programs accessed the data files, interpreted and coordinated the data into data sets, performed required computations and returned the results to the data files for display or subsequent analysis. Although the complete system is relatively complex, the analysis approach was a straightforward, step-by-step progression of selecting appropriate conditions to be analyzed, preparing the required data, and coordinating the resultant data sets. Traditional computer programs then automatically generated the flood hazard, flood damage potential and environmental implications of proposed future development.

Greater detail was accommodated by interrupting the computer analysis at appropriate stages and substituting more specific or refined data for the generalized data automatically generated by the system. The efficiency, flexibility and compatibility of this study approach allowed for presentation of a complete array of cause-effect relationships in terms familiar to agencies and individuals faced with choices among alternative future development plans and policies.

The integrated use of proven analytical methods and state-of-the-art computer techniques for the grid cell data bank produced an overall study methodology with many advantages. This spatial data management and comprehensive analysis system provided for:

- A centralized, coordinated set of data, in grid cell form, that a computer easily stores and accesses
- Dynamic analysis capability through consistent and systematic assessments by automated techniques
- Multi-purpose assessments in hydrologic, hydraulic, economic and environmental terms for comprehensive land use planning
- Flexibility in scope and detail of analysis with applied computer techniques while still preserving and requiring engineering judgement
- A permanent, easily updated set of data that can document and support results of the study, provide additional secondary information for planning purposes, and form the basis for future use.

Figure 1 is a general representation of the overall spatial data management and analysis methodology.

Data Bank Management

This phase of the study included the key elements of data collection, data encoding, data processing/editing, and data bank creation. These tasks accounted for a major portion of the overall work effort and led to the development of the grid cell data bank upon which the entire study methodology was built.

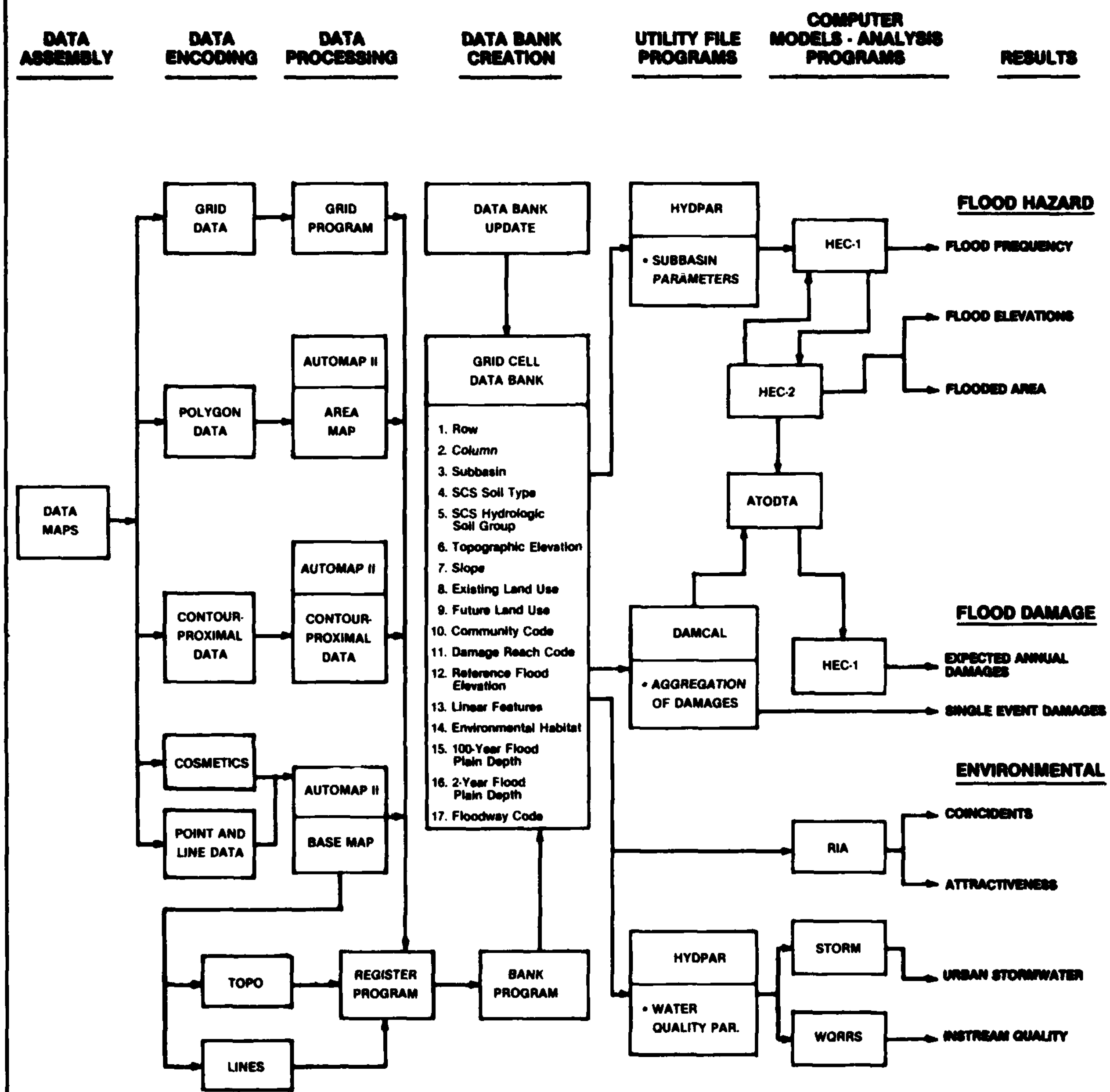


FIGURE 1

DATA MANAGEMENT AND MODELING PROCESS

The creation of the grid cell data bank began by subdividing the 56-square mile area of the Pennypack Watershed into sequentially smaller and smaller spatial units to facilitate recording necessary physiographic characteristics. These spatial units were, in decreasing order of magnitude: watershed, sub-basin, flood plain area, damage reach and, finally, grid cell boundaries.

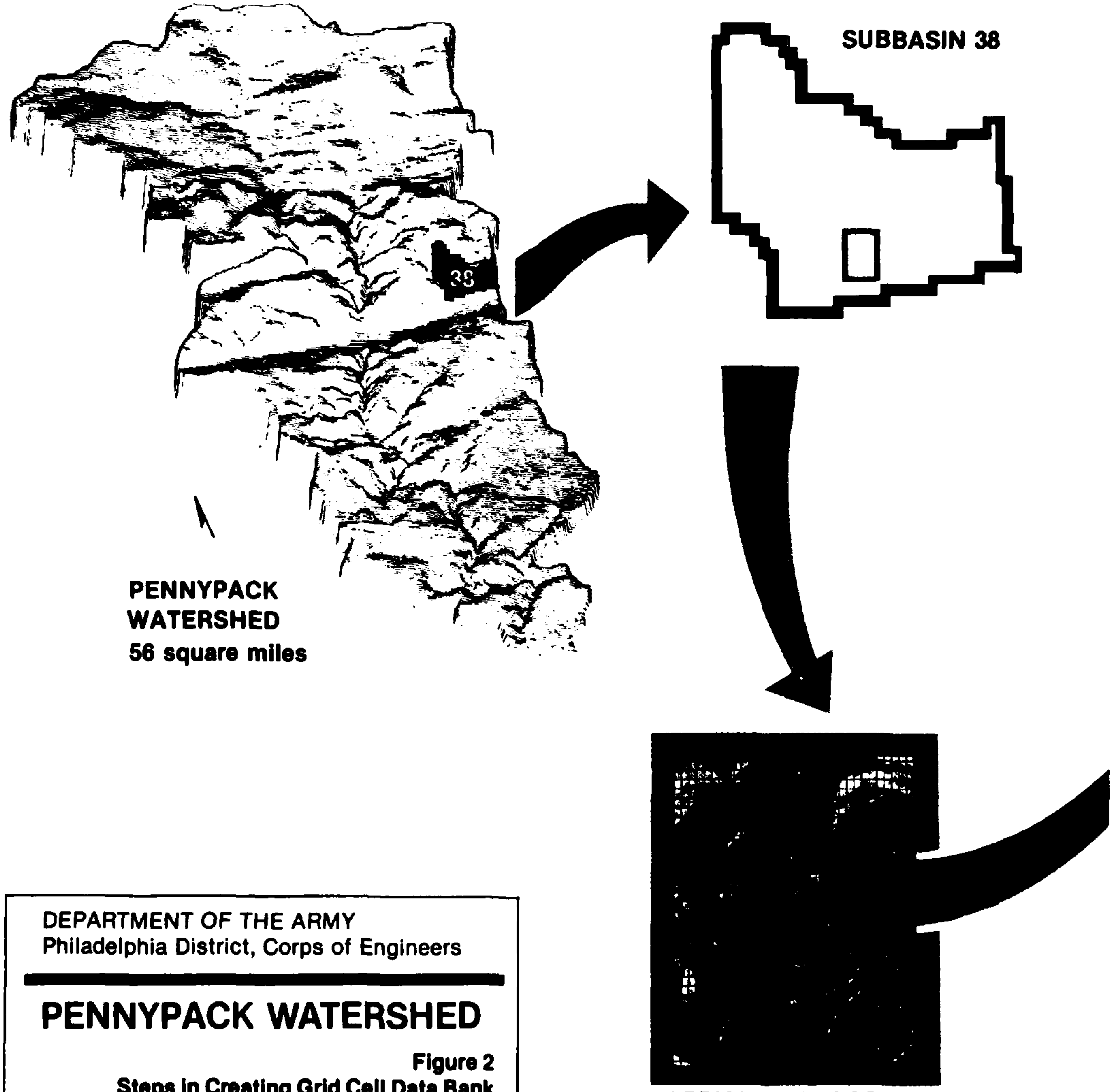
The grid cell concept was incorporated in the methodology as a convenient and efficient means of converting raw spatial data, such as mapped land use, to a digital form that the computer can systematically store and manipulate. A schematic representation of the structure of the grid cell data bank and its relationship to other spatial units in the watershed is shown in Figure 2.

A grid system oriented approximately parallel to the State Plane and Universal Transverse Mercator (UTM) coordinate systems was first superimposed over the watershed to subdivide its total area into uniform spatial units or cells. Each cell was then assigned a series of numerical values representing physiographic characteristics such as elevation, slope, soil type and ground cover. These grid cells are the basic unit for data management, with the data stored in digital (numerical) form. Special-purpose computer programs then accessed the cells either individually or in select groups for desired analyses or display. A rectangular grid cell with a horizontal-to-vertical dimension ratio of 0.8:1.0 was selected for use in the study. This selection was designed to be compatible with standard character sizes on most computer printers, thereby enabling the computer to automatically generate mapped output of grid cell data from the data bank.

Because varying types of analyses were to be performed throughout the study, each with its own particular data needs and desired level of detail, two distinct grid cell data banks were developed. One data bank covers the entire 56-square mile area with grid cells representing an area of 160' x 200' (approximately 0.75 acre) at a base map scale of 1:4800 (1" = 400'). This data bank included the full array of variables required for use in the study, and contains approximately 49,000 grid cells.

A second data bank covering only floodplain areas was constructed using smaller grid cells representing an area of 80' x 100' (approximately 0.20 acre) at the base map scale. This second data bank was developed primarily for use in economic analyses where a more refined resolution of such data variables as land use and elevation was considered appropriate for more accurate assessments of flood damage potential. This data bank contains approximately 35,000 grid cells.

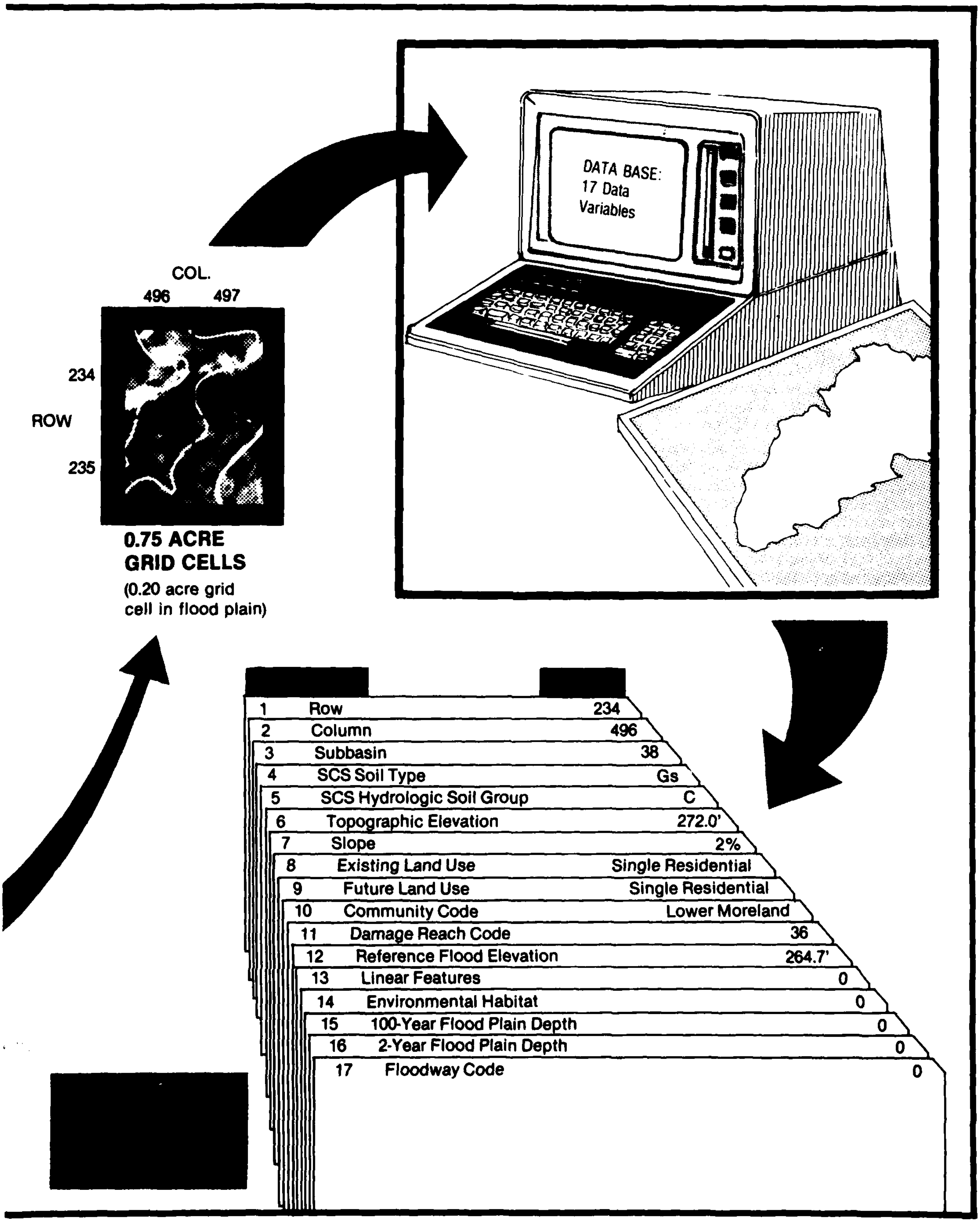
Steps in Creating Grid Cell Data Bank



DEPARTMENT OF THE ARMY
Philadelphia District, Corps of Engineers

PENNYPACK WATERSHED

Figure 2
Steps in Creating Grid Cell Data Bank


DATA BASE:
17 Data
Variables
COL.
496
497
234
ROW
235
0.75 ACRE
GRID CELLS
(0.20 acre grid
cell in flood plain)
1 Row 234
2 Column 496
3 Subbasin 38
4 SCS Soil Type Gs
5 SCS Hydrologic Soil Group C
6 Topographic Elevation 272.0'
7 Slope 2%
8 Existing Land Use Single Residential
9 Future Land Use Single Residential
10 Community Code Lower Moreland
11 Damage Reach Code 36
12 Reference Flood Elevation 264.7'
13 Linear Features 0
14 Environmental Habitat 0
15 100-Year Flood Plain Depth 0
16 2-Year Flood Plain Depth 0
17 Floodway Code 0

DATA COLLECTION

General Methodology

The basic data required for the study included a full range of watershed characteristics necessary for comprehensive flood hazard, flood damage and environmental assessments.

Because the goals of the study were to assess the impacts of changing land use in the watershed, existing and alternative future land uses were, of course, key data inputs to the analyses. Other essential data variables included soil classification data obtained from soil survey maps for Bucks, Montgomery and Philadelphia Counties at a scale of 1:158400 (1" = ¼ mile). These maps were prepared by the Soil Conservation Service (SCS), U.S. Department of Agriculture, the Pennsylvania State University, College of Agriculture, and the Pennsylvania Department of Environmental Resources, State Soil and Water Conservation Commission.

Soils data was essential (along with land use and slope) for assessment of possible future runoff from the watershed. Another essential data input was ground elevation (and corresponding surface slope) needed to relate potential runoff to flood depths, and flood damages. Elevation data was obtained as a by-product of orthophoto base map production (see Base Mapping) and additional stream channel and floodplain elevations and geometry were obtained from field surveys conducted by Philadelphia District personnel.

All data variables were collected or developed from the most appropriate and accurate sources available. Where necessary, specific data were developed exclusively for the study, such as conceptual future land use alternatives. Other data sets were automatically generated from basic data already in the grid cell data bank, such as the development of the land surface slope variable from the grid cell data file of topography. Categories of source data in the study include:

1. Spatial or areal data (such as land use and soil type)
2. Contour data (such as topography)
3. Linear data (such as transportation routes and utilities)
4. Point data (such as reference points)

Existing and Future Land Use Conditions

General

Since existing and future land use patterns were essential components of the grid cell data bank, the flood hazard, flood damage and environmental impacts identified by this study were keyed to changes in land use both on and off the floodplain. Identical land use categories were required for both existing and future conditions in order for meaningful and valid comparisons to be made. *Special emphasis* was placed, therefore, on the development of general land use categories that (1) would be reasonably representative of existing conditions; (2) could be reasonably estimated for future land use conditions.

Land use categories were selected for the following reasons:

- Reasonable compatibility with other local and regional land use projections
- Easy identification from existing land use mapping and tax records, and verification by visual inspection with low-altitude aerial photography
- Meeting technical requirements of the study by being responsive to the hydrologic, economic and environmental requirements of the modeling
- Allowing more refined classifications of categories if required for future analyses

TABLE 3

MAJOR DATA VARIABLES

1	Row
2	Column
3	Subbasin
4	SCS Soil Type
5	SCS Hydrologic Soil Group
6	Topographic Elevation
7	Slope
8	Existing Land Use
9	Future Land Use
10	Community Code
11	Damage Reach Code
12	Reference Flood Elevation
13	Linear Features
14	Environmental Habitat
15	100-Year Flood Plain [illegible]
16	5-Year Flood Plain [illegible]
17	Floodway Code

Because all analyses required a consistent set of land use categories, those selected for the study were chosen as the result of a compromise among hydrologic, economic and environmental disciplines. For example, a single category of a particular land use might be sufficient to accurately reflect the runoff characteristics related to the type and impervious nature of the land cover — thereby satisfying hydrologic (runoff) requirements. However, several sub-categories of that same land use might be required to accurately reflect varying degrees of flood damage potential related to the size, type, value and use of both structure and contents, in order to satisfy economic requirements. The land use categories adopted for the study met these multi-purpose requirements and allowed for rational and consistent assessments of flood hazard, flood damage and environmental impacts of changing land use conditions.

Table 4 lists the 14 adopted basic land use categories for both existing and future land use conditions evaluated in the study.

TABLE 4

LAND USE CATEGORIES

- **Single Family Residential**
- **Twin and Row Homes**
- **Apartments**
- **Industry**
- **Transportation**
- **Communications and Utilities**
- **Commercial Services**
- **Community Services**
- **Recreation and Cultural Areas**
- **Agriculture**
- **Military**
- **Mining**
- **Forests and Undeveloped Land**
- **Water Bodies**

Existing Land Use

Existing land use in the Pennypack Watershed was needed to establish base conditions for flood hazards, flood damages and environmental factors to which alternative future conditions could be compared. The Bucks County Planning Commission provided detailed tax mapping at a scale of 1:4800 (1" = 400'), and the City of Philadelphia provided detailed tax mapping at a scale of 1:2400 (1" = 200'). The Delaware Valley Regional Planning Commission (DVRPC) provided 1:4800 (1" = 400') interpreted aerial photography of existing land use for Montgomery County as of 1975.

Existing land use data from these sources were aggregated into the 14 adopted land use categories for use in the study and overlaid to the 1" = 400' orthophoto base mapping of the watershed. Land use delineations were then visually checked for accuracy and updated where necessary. Field observations and low-altitude aerial photography were also used to update existing land use information as accurately as possible to these conditions.

The resultant Existing Land Use Conditions indicate that the watershed is approximately 64% urbanized, with the most predominant land uses being the residential categories which cover 47% of the urbanized watershed area. The remaining 36% of the watershed is undeveloped.

Future Land Use — General

To make reasonably accurate comparisons between existing and future conditions in the Pennypack Watershed, a rational set of alternative future land use plans was needed. However, a wide range of factors affect future land use, many of which were beyond the scope of this study. Therefore conceptual, rather than site-specific, projections of future land use conditions were developed.

At a meeting in the Philadelphia District Office, representatives of the Montgomery County Planning Commission, the City of Philadelphia, the Bucks County Townships of Upper Southampton and Warminster, and the Pennypack Watershed Association collectively developed several alternative schemes of future land use conditions. The representatives who participated in this decision-making process were knowledgeable about the social, political, economic and environmental trends in the area that could influence future development.

In order to insure compatibility between existing and alternative future land uses, the group was provided with computer-plotted existing land use mapping of the watershed from the grid cell data bank. This mapping was overlaid on base mapping of the watershed to allow visual inspection of other important development factors such as land surface elevation, slope and existing ground cover. Areas within the watershed representing "undeveloped" land use under existing conditions, were modified by the watershed representatives to reflect their collective estimates of potential future land use conditions. Three conceptual future land use plans were suggested for analysis:

Alternative A: Continued development with general environmental constraints on steep slopes, prime open space and flood plain areas.

Alternative B: Continued development following existing patterns, but without constraints.

Alternative C: Continued development in accordance with existing land use zoning.

These alternative plans do not represent specific land use at any given point in time, but represent reasonable estimates of future land use based on current trends and attitudes.

TABLE 5				
LAND USE COMPARISON FOR WATERSHED				
		% of Watershed Alternative Land Use Plans		
Land Use Category	Existing Conditions	Alternative A	Alternative B	Alternative C
1. Single Residential	36	38	47	51
2. Twins and Row Residential	7	8	9	9
3. Apartments	4	5	5	5
4. Industry	4	6	7	9
5. Transportation	3	3	3	3
6. Communication and Utilities	1	1	1	1
7. Commercial	5	5	6	6
8. Community Services	4	4	4	4
9. Military	0	0	0	0
10. Recreational and Cultural	5	5	7	5
11. Agriculture	9	7	1	1
12. Mining	0	0	0	0
13. Forests and Undeveloped	21	17	9	5
14. Waterbodies	1	1	1	1
	100%	100%	100%	100%

Alternative A Land Use Plan

This scheme used existing developmental trends and pressures as a base, but prohibited future development that would otherwise occur on land surface slopes greater than 15%, or on productive agricultural land and prime forested land. The imposition of these constraints produced an alternative land use scheme that represents approximately 70% urbanization in the watershed — a modest 6% increase over existing conditions. Of the urbanized areas, 51% of the development is in the residential categories compared to 47% under existing conditions.

Alternative B Land Use Plan

This represents future development in the watershed occurring without the benefit of specific land use management policies or controls. This plan allowed currently undeveloped areas to develop as might be expected under existing trends. This conceptual future represents a watershed that is 82% urbanized — an 18% increase in development over existing conditions. Of the urbanized area, 61% is residential development, compared to 47% under existing conditions. Only 18% of the watershed would remain undeveloped under this plan — exactly one-half of the undeveloped area under existing conditions.

Alternative C Land Use Plan

This represents full development of the watershed in compliance with existing zoning restrictions in each of the 12 municipalities in the watershed. It was considered to be a very rational alternative, since zoning is already a legally enforceable land use management tool in use throughout the watershed. This land use plan was created by modifying the data base to represent all currently undeveloped land being developed in the future according to existing local zoning requirements. Although zoning variances are anticipated to occur, they could not be accurately estimated and were therefore not included in developing Alternative C.

It is important to note that some communities have adopted holding zones for public lands at the lowest possible density of development. This may result, for example, in publicly-owned land being zoned for low-

TABLE 6

LAND USE COMPARISON BY COMMUNITIES

Community	Land Use	Existing Conditions	Alternative A	Alternative B	Alternative C
Abington Township	Residential	53	57	74	80
	Industry/Commercial	4	4	4	5
	Agriculture/Undeveloped	33	29	6	2
	Other	10	10	16	13
Borough of Bryn Athyn	Residential	18	21	56	58
	Industry/Commercial	0	1	5	5
	Agriculture/Undeveloped	64	63	10	10
	Other	18	15	29	27
Borough of Hatboro	Residential	64	66	67	70
	Industry/Commercial	18	18	19	19
	Agriculture/Undeveloped	8	6	4	1
	Other	10	10	10	10
Horsham Township	Residential	35	44	66	71
	Industry/Commercial	8	12	17	21
	Agriculture/Undeveloped	50	37	9	1
	Other	7	7	8	7
Jenkintown Township	Residential	77	77	78	77
	Industry/Commercial	18	18	18	18
	Agriculture/Undeveloped	5	5	3	3
	Other	0	0	1	2
L. Moreland Township	Residential	44	46	67	74
	Industry/Commercial	6	6	9	9
	Agriculture/Undeveloped	38	36	10	5
	Other	12	12	14	12
City of Philadelphia	Residential	46	47	49	52
	Industry/Commercial	14	17	18	20
	Agriculture/Undeveloped	27	21	18	14
	Other	14	15	15	14
Borough of Rockledge	Residential	83	83	83	83
	Industry/Commercial	11	11	11	11
	Agriculture/Undeveloped	1	1	1	1
	Other	5	5	5	5
Upper Dublin Township	Residential	63	70	92	93
	Industry/Commercial	3	3	4	3
	Agriculture/Undeveloped	32	25	3	2
	Other	2	2	1	2
U. Moreland Township	Residential	50	54	65	69
	Industry/Commercial	9	10	13	16
	Agriculture/Undeveloped	28	22	7	2
	Other	13	14	15	13
U. Southampton Township	Residential	59	63	66	70
	Industry/Commercial	13	20	20	21
	Agriculture/Undeveloped	22	11	7	6
	Other	6	6	7	3
Warminster Township	Residential	60	62	62	61
	Industry/Commercial	11	11	11	12
	Agriculture/Undeveloped	13	11	10	10
	Other	16	16	17	17

(Column group heading: % of Watershed Alternative Land Use Plans)

density residential development, although its existing and probable future land use would be as park land or open space. For the purposes of this study, all assessments of the Alternative C Land Use Plan were made to show the impact of full watershed development in accordance with the maximum land use (density) permitted under local zoning, although actual or probable land use may differ.

The resultant plan characterizes a watershed that is 88% urbanized, with 65% of that development being in the residential categories. This percentage of residential development alone is greater than the entire degree of urbanization (64%) under existing conditions. This plan also represents a watershed scenario where only 12% of the total area is left undeveloped — just one-third that of the existing undeveloped open space areas.

Other Land Use Plans

In addition to the alterative land use plans developed as a cooperative effort among watershed representatives, a fourth estimate of future land use patterns was analyzed. This was based upon future projections developed by the Delaware Valley Regional Planning Commission (DVRPC). Land use in the Pennypack Watershed was extracted from a much larger, regional study of projected growth in the Delaware Valley area of southeastern Pennsylvania, based on population and employment demands estimated for the year 2000. This future land use scheme was requested by several planning and governmental agencies in the watershed. It was felt that since the DVRPC Year 2000 Plan was an integral part of several other studies being conducted for comprehensive planning purposes in the region, it should be considered an easily recognizable and institutionalized plan.

Because this regional land use projection was mapped to a different scale (1" = 1 mile) and subdivided into only eight basic categories, it was analyzed separately, and compared only to DVRPC estimates of existing land use that were developed by similar criteria and mapped to comparable scales. These base conditions (existing development) and Year 2000 Plans were also analyzed only as conceptual land use schemes without regard to potential land use management or flood plain regulatory policies. Results of these analyses are available upon request.

Table 5 lists percentages of the total watershed represented by the 14 major land use categories under Existing and Alternative Land Use Plans for the Pennypack Watershed.

Table 6 shows comparative percentages of land use for each of the 12 municipalities in the watershed.

Plates 6, 7, 8 and 9 (see pages 34-41) depict these land use patterns in grid cell form. For clarity, the 14 land use categories have been aggregated into 11 color-coded separations; water bodies and stream channels are not shown in grid cell form.

Base Mapping

During the data collection phase of the study, new base mapping was prepared for the area. The entire watershed was covered by new aerial photography (March 1977) at a scale of 1:24,000 (1" = 2000'). Orthophoto map sheets were prepared to produce scalable base mapping free from distortions at a scale of 1:4800 (1" = 400').[2] Pennsylvania State Plane Coordinate and Universal Transverse Mercator (UTM) Grid Systems were prepared as overlays to the orthophoto map base, as were conventional 4-foot contour interval topographic overlays. Two additional rectangular grid systems were prepared and added to the mapping to establish grid cell boundaries to be used later in data encoding. The resultant orthophoto base mapping was also used for visual inspection of existing land use patterns, topography and other cultural and environmental features, and served as an accurate base map to which all grid cell data were registered.

More information on orthophotography and its use for obtaining digital topographic data is available on request.

DATA BANK CREATION

Data Encoding

As defined for this study, data encoding is the process by which source data were converted to a grid cell format for subsequent processing into a computerized data bank. Two basic data encoding techniques were adopted for use in this study.

The first is called grid cell encoding. It uses a transparency of the grid cell network as an overlay to a mapped data variable. By visual inspection, each grid cell was manually assigned a numerical value representing individual categories of the data variables being encoded. This method was appropriate for several data variables used in the study, particularly where the area being encoded was relatively small, and where the nature of the data required site-specific judgements on a cell-by-cell basis. Grid cell encoding would have been far too time-consuming and costly to be used for every variable to be entered into the grid cell data bank, particularly for those data variables covering the entire watershed. Therefore, a more efficient and sophisticated procedure for data encoding, called digitization, was also used.

Digitization is an automated technique for converting mapped data to a form that can be stored and manipulated by a computer. This is accomplished by redefining the irregularly-shaped area (or polygon) of a data variable such as land use or soil type by a series of straight-line segments that closely approximate the original area. The endpoints, or vertices, of these connected straight-line segments are assigned coordinate values to record the spatial extent of each category of the variable being encoded. This procedure can be accomplished manually but is more suitable for automatic digitizing equipment, which can rapidly record and store coordinate values as an operator traces the outline of the area to be digitized. Further computer processing was then required to convert the digitized data to grid cell format.

Most data variables in this study were encoded by automatic digitizing techniques using specialized equipment. These digitizing procedures were efficient for rapidly converting spatial data to a digital grid cell format. Because the data were not encoded directly into a fixed grid system, flexibility of grid cell sizes can be achieved by appropriate computer processing to accommodate varying levels of detail. Also, the identity of the original data is maintained and can later be remapped by the computer in a conventional form free from grid cell subdivisions. The flexibility of the overall methodology allowed both grid cell encoding and digitizing methods to be utilized in this study, with the more appropriate technique selected for each data variable.

More detailed information regarding data encoding procedures and techniques may be found in "Guide Manual for the Creation of Grid Cell Data Banks".[3]

Data Processing and Editing

After the basic data were encoded, further computer processing and editing were required before the data could be stored in the grid cell data bank. Grid cell encoded data were first processed using a modified version of the computer program AUTOMAP II.[4] This created a temporary grid cell file of the data at the source map scale, and produced computer printed graphical output of the data variable as it was encoded. Alpha-numeric characters representing grid cell assignments of individual categories of data were compared to the source mapping to check for errors. After this editing was completed, errors were corrected by re-encoding affected cells.

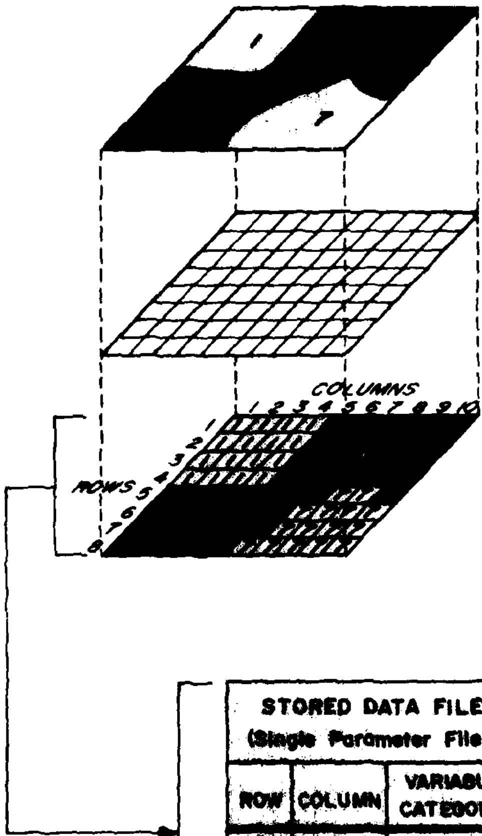
Digitized data required several additional steps for processing and editing. As a first step, the digitized data variable was replotted by the computer using the coordinate values recorded by the digitizing equipment. The resultant map was then overlaid on the source mapping to check visually for errors. The digitized data were then edited by a computer program designed to check automatically for small gaps or overlaps in digitized data. These editing procedures insured that the digitized data accurately represented the spatial extent and arrangement of each data variable as it existed on the original source mapping.

Because the grid cell data bank was constructed by stacking data overlays in the memory of the computer, it was essential that each overlay be accurately aligned to a common base map. This necessary adjustment in alignment (or registration) of edited, digitized data was accomplished automatically by the computer program REGISTER.[5] This program uses mathematical relationships to compensate for differences in origin (displacement), scale (size), rotation and distortion between individual data source maps and a common base map. A system of over 500 reference points such as street and railroad intersections, common to both source mapping and the orthophoto base mapping, were identified for use by the REGISTER program.

After the grid cell encoded or digitized data were edited and properly registered, a final processing step was required to create grid cell files of the encoded data. This conversion was performed by the program AUTOMAP II, which also produced computer-printed graphical output of each mapped data variable.

After appropriate processing and editing, grid cell representations of cell-encoded or digitized data generated by AUTOMAP II were ready for insertion into the grid cell data bank. The computer program BANK[6] was used to systematically stack grid cell data by row-and-column identification onto magnetic tape. Data stored in this uniformly stacked arrangement are easily accessible by individual grid cell addresses, (row/column identification), by select groups of cells (such as subbasins or damage reaches), or as complete data variable(s) for any desired analysis or display.

SCHEMATIC OF DATA ENCODING



STORED DATA FILE (Single Parameter File)		
ROW	COLUMN	VARIABLE CATEGORY
1	1	1
1	2	1
1	3	1
1	4	1
1	5	5
1	6	5
.	.	.
.	.	.
	(etc.)	

FIGURE 3

OVERVIEW OF COMPUTER MODELING AND COMPREHENSIVE ANALYSES

The second major phase of the study, following the creation of the grid cell data bank, was the application of a system of automated techniques for computer modeling and analysis. The task of obtaining basin modeling data was automated so that large-scale, relatively rapid analysis of future land use patterns was possible. To the maximum extent practicable, "traditional" methods for conducting basic flood hazard, economic and environmental analyses were incorporated in the study methodology.

Technical assessments were generally performed by standard Corps computer programs modified to accept grid cell data. To the maximum extent practicable, these programs were linked by secondary utility programs to produce an automated, systematic analysis procedure that operates directly from the data bank.

The flood hazard evaluation was conducted by first performing routine statistical analyses of streamflow gage records, and constructing a standard HEC-1 rainfall-runoff model[7] of the watershed in order to determine potential flood flows of various frequency events under existing land use conditions. These hydrologic results were then reproduced by other computer programs using techniques of the Soil Conservation Service that relate runoff to land use, soil type and surface slope. Since these data were readily available in grid cell form, the linked system of computer programs was then used to perform rainfall-runoff analyses for identified alternative future conditions by directly accessing the data bank. Once potential floodflows had been developed, the standard HEC-2 Water Surface Profile computation program[8] was used to predict flood depth and areas of inundation.

The computer modeling was further extended to provide automated assessments of flood damage potential. Specialized computer programs were used to automatically extract floodplain grid cells and corresponding land uses directly from the data bank, and identify their elevation-damage susceptibility. These data were then combined with potential flood evaluation data and aggregated to yield single-event and average annual flood damage assessments at key index locations within identified damage reaches. In this way, flood hazard and flood damage evaluations were linked to each other and to the data bank for systematic and consistent assessment of land use change.

Environmental assessments were also performed, and automated as fully as possible, to take advantage of the capabilities of the data bank. A series of newly developed Resource Information and Analysis (RIA) computer programs[9] was used to access the data bank and display physiographic or ecological features of interest. These computer programs were also used to perform and map basic environmental assessments such as distance determinations, coincidence of features, impact assessment, and locational attractiveness for a variety of environmental concerns that may be important in local land use planning. Preliminary water quality analyses were performed using available grid cell land use data and an in-stream water quality module of the standard Corps program STORM.[10] General habitat classification was compiled, and the data bank was manipulated to display impacts on habitat and species that may be expected as the watershed continues to develop.

FLOOD HAZARD EVALUATION

General

Floods have occurred in the Pennypack Watershed during all seasons of the year. In the tributaries heavy rainfalls of short duration, such as summer thunderstorms, cause most flooding problems by inundating low-lying roads. Major floods of the Pennypack Creek, however, result from long-duration storms such as hurricane activity. Whenever major rainfall occurs, stages can rise from normal flow to extreme flood peaks in a short time with high velocities in the main stream channel.

Published accounts of damaging floods in the study area date back as early as July 14, 1931. Although the watershed had experienced floods earlier than 1931, only fragmentary information is available before then. Other floods causing significant damage occurred in 1950, 1967, 1971 and 1975.

Floods of the same or larger magnitude as those experienced in the past could occur in the future. The objective of the flood hazard evaluation for this study was to determine probable flood flows and elevations for flood events of various frequencies for Existing and Future Land Use conditions. This analysis consisted of a hydrologic evaluation to define flows and frequencies, and a hydraulic evaluation to relate flood flow to flood elevation.

Hydrologic Analysis

The hydrologic analysis was conducted to determine the relationship between rainfall and stream flow. For the purpose of this study, the relationship was keyed to the existing and potential future land uses in the watershed. In this way, as land use changes, the resulting impact on stream flows can be determined by simulating the runoff response to changing land use. An HEC-1 model[7] was constructed for this purpose, and calibrated and verified for existing land use conditions based on available stream flow and rainfall records. The model was then used to simulate stream flow based on land use changes as presented in Alternative Land Use Plans A, B and C.

The Pennypack Watershed was subdivided into a total of 65 sub-basins to facilitate estimating a consistent set of discharge-frequency values at identified index points for existing and future conditions. Plate 2 is a computer-plotted map showing the 65 subbasin locations in the data bank. Gages with rainfall and streamflow records were identified, and data were obtained from the National Weather Service and U.S. Geological Survey. Gage locations are shown on Plate 3.

Several methods were used to estimate unit hydrograph (basic runoff) characteristics for each of the 65 subbasins. Initially, the unit hydrograph and exponential loss theory was evaluated using the unit hydrograph optimization routine of the HEC-1 program.

Discharge frequencies were statistically estimated for five stream gage locations within the basin, based on available annual series data. Rainfall intensity-frequency-duration curves were developed from the National Weather Service Technical Paper 40.[11] Hypothetical storm events of selected frequencies were developed and runoff estimates generated by the HEC-1 model. Unit hydrograph and loss rates were adjusted to obtain results reasonably consistent with historical storm events and statistically derived discharge-frequency data.

After land use and surface slope became available from the data bank, the rainfall-runoff model was adapted to the Soil Conservation Service (SCS) "Curve Number" method[12] for developing unit hydrographs. The SCS method accommodates a consistent procedure of evaluating the effects of forecasted land use changes on runoff rates from a data bank structure.

Fourteen different categories of land use were designated to distinguish among different runoff characteristics. Each category was assigned an average percent of impervious area and a typical SCS curve number. The data processing interface computer program HYDPAR[13] developed by the HEC was used to retrieve these data variables from the data bank. This program also computed the SCS unit hydrograph parameters for each sub-basin which were then used in the simulation of stream runoff with the HEC-1 computer model. The ATODTA computer program,[14] which was also developed by the HEC, was used as a link between these two models.

An index rainfall event was selected with ratios defining the full range of the discharge-frequency curves previously developed for each sub-basin. The 25-year rainfall event was selected as a reasonable intermediate event for use as the index storm. Ratios of the index storm were selected to bracket all possible flood events, the lowest value resulting in a non-damaging discharge and the highest value resulting in a discharge greater than a 500-year frequency event. The HEC-1 model computed the discharges for each specified ratio of the index storm, and then evaluated the average annual damage for each plan of development.

Complete information on the hydrologic methodology of this study can be found in "Special Projects Memo, 78-7, Pennypack Creek XFPI, *Hydrology*".[15]

Hydrologic Impacts

Each of the three Alternative Land Use Plans for future development was analyzed for its impact on runoff. Although these conceptual plans represent from 6% to 24% increases in total development over

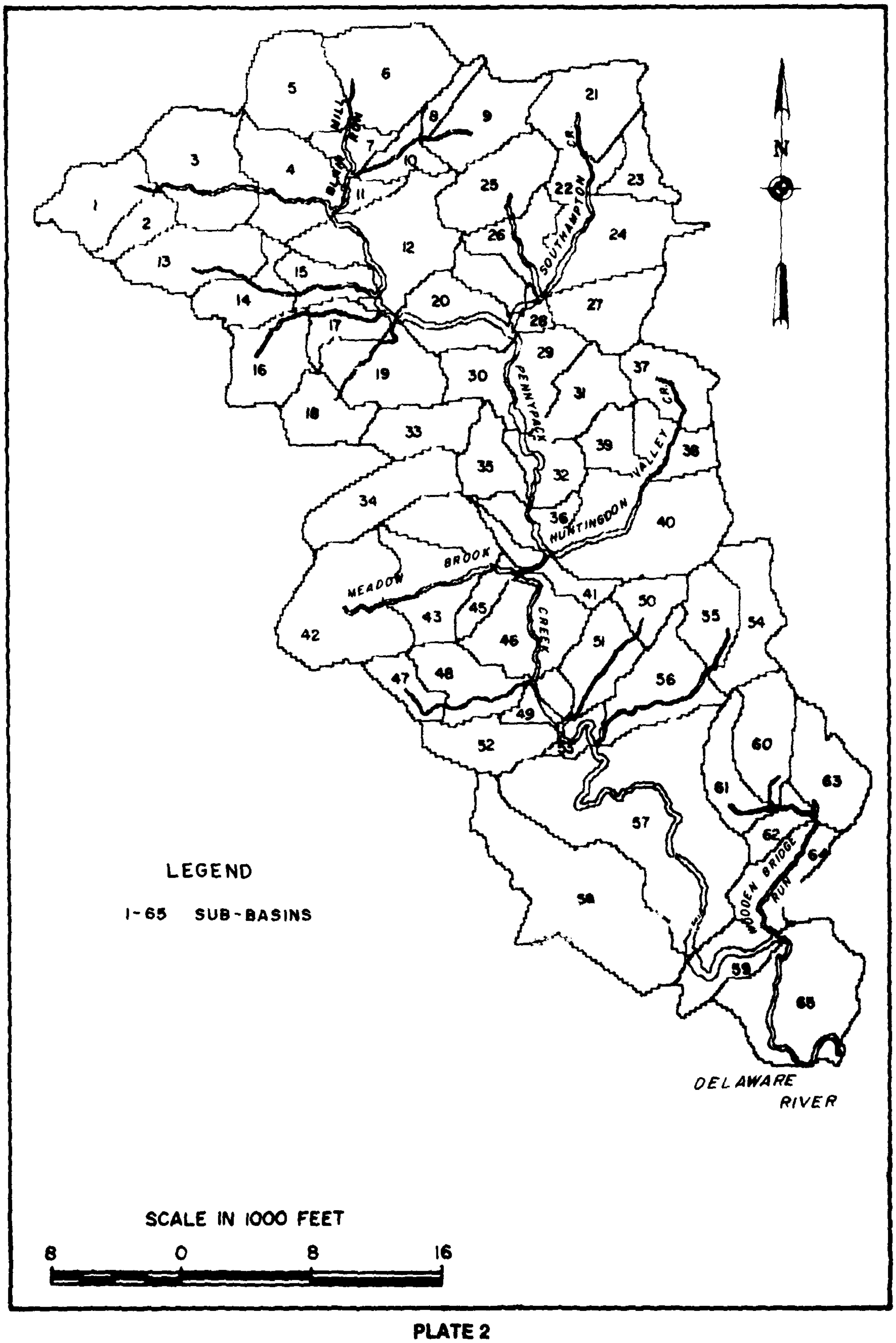


PLATE 2
SUB-BASIN INDEX

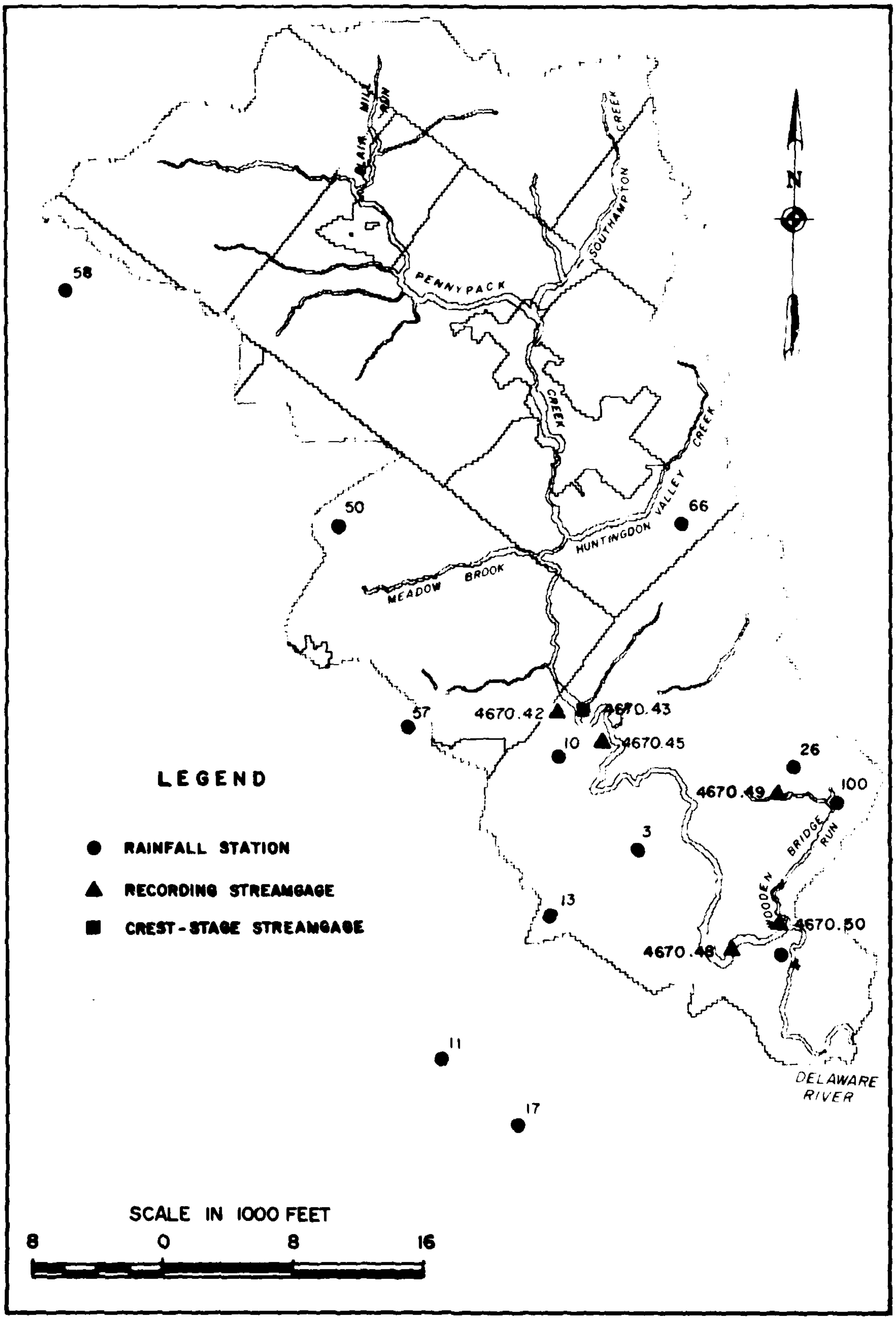


PLATE 3
LOCATION OF RAINFALL STATIONS AND STREAM GAGES

existing conditions, overall impacts on runoff are low for the watershed as a whole.

The hydrologic characteristics of the watershed tend to dampen out individual sub-basin impacts as floodflows travel downsteam. The size, shape, slope, soil type and land use (for existing and future conditions) of each sub-basin all contribute to local runoff impacts, many of which are significantly higher than the cumulative impacts that might be observed at the mouth of the Pennypack Creek.

For this reason, the main stem Pennypack Creek shows less of an impact to future development than tributary areas, especially in the lower reaches toward the confluence with the Delaware River. These differences are in some degree the result of valley storage factors that affect floodflows and travel time near the outlet of the watershed.

For example, local increases of up to 20% for 100-year floodflows, and up to 36% for 10-year floodflows were found for specific sub-basins and damage reaches through the watershed. In general, the runoff was found to increase more for the more frequent flood events. Table 7 tabulates impacts of alternative future development on 10-year and 100-year floodflows by damage reach and community. Because impacts vary widely, local cause-effect relationships between land use change and runoff should be examined closely before land use management decisions are made.

Hydraulic Analysis

The hydraulic analysis was conducted to determine the depth of flow and area of inundation for flood events of various frequencies, in order that comparative assessments could be made between existing and future conditions. The HEC-2 Water Surface Profile computer program[8] was used to combine rainfall-runoff relationships from the hydrologic analysis with stream channel, bridge, dam and floodplain geometry. The purpose was to determine water surface elevations for the 2-, 10-, 50-, 100-, and 500-year frequency floods. In this evaluation, floodplain characteristics were obtained from topographic data obtained as part of the orthophoto base mapping, and by field surveys for Pennypack Creek and 15 tributaries.

Utilizing the flood depth information obtained, supplementary programming was used to determine those areas of the grid cell data bank (representing existing and future land use conditions) that would be inundated by the various frequency flood events. Rating curves of floodflow/flood depth relationships were also developed at key index locations for subsequent flood damage computations. In conjunction with the backwater analysis of existing land use conditions, a regulatory floodway was also determined, in general accordance with guidelines established for the National Flood Insurance Study Program. The resultant floodway was then encoded into the data bank for later analysis of its effectiveness as a flood plain management policy to reduce future flood damage potential. Plate 4 is an example of computer-plotted grid cell delineations of the regulatory floodway and 100-year floodplain for existing conditions as modeled in the data bank.

Hydraulic Impacts

Each of three alternative future land use plans was analyzed for its impact on flood depths and flooded areas. The hydraulic analysis shows that overall impacts are moderate. Flood depths generally increased by only 1.0 to 1.5 feet over existing flood levels for the 10-, 50-, 100-, and 500-year flood events. Again, impacts vary widely throughout the watershed based on local conditions. However, the trends were observed to run somewhat opposite to impacts seen in the hydrologic analysis. Although sub-basins in tributary areas generally produced higher relative percentage increases in runoff for future conditions, the steeper slopes in these areas caused flood waters to drain somewhat faster than on the main stem, without appreciably adding to flood depth or inundated area. Along the main stem Pennypack Creek, where increases in peak flows were generally lower, the milder stream slopes produce higher relative flood elevations. Impacts in the watershed generally increased more significantly for the more frequent flood events. For example, under the Alternative C Land Use Plan (which represents the most urbanized condition), total inundation by a 2-year flood event would increase by approximately 45% whereas for the 100-year flood event, only 3.3% more area would be flooded than under existing conditions.

These impacts, though moderate, were used in subsequent flood damage evaluations for existing and alternative future conditions. In general, the impacts of future development in the watershed represented by the three alternative land use plans are evident more as a result of the location of future development (e.g. in flood plain areas) than the density of future development causing large increases in floodflows or flood depths.

Table 7

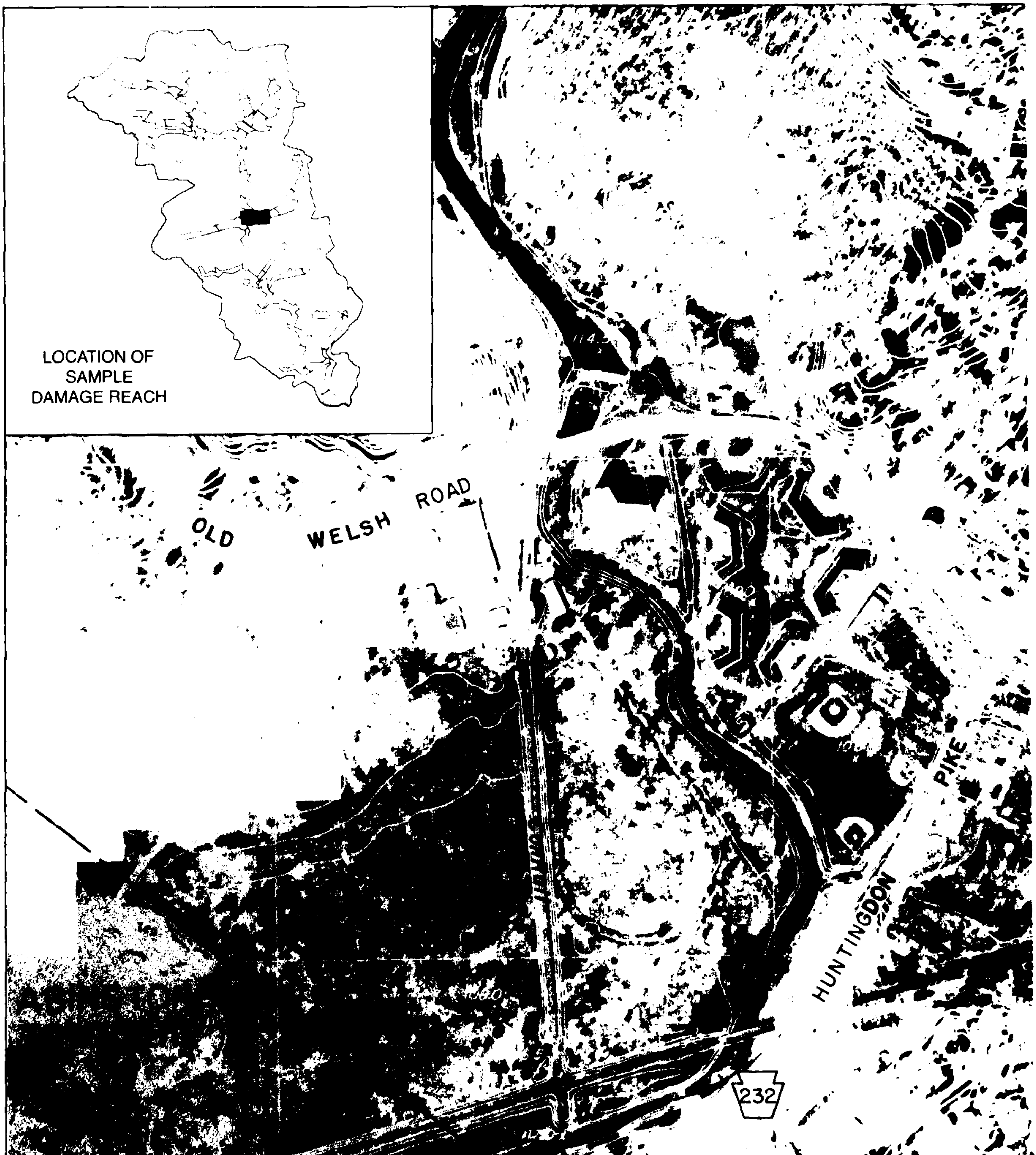
IMPACTS OF ALTERNATIVE FUTURE DEVELOPMENT PLANS ON RUNOFF

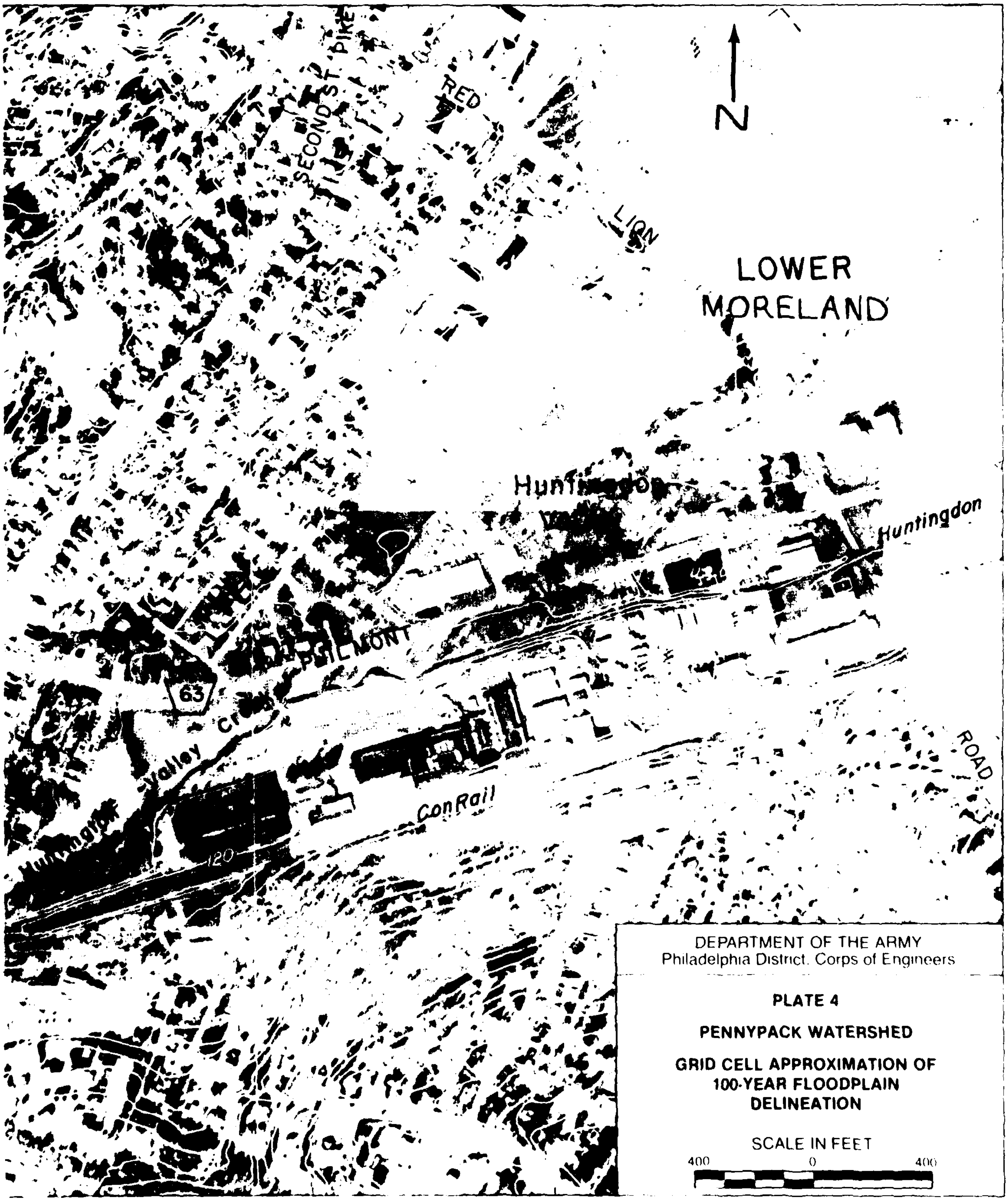
		% Increase in Runoff 10-Year Flood			% Increase in Runoff for 100-Year Flood		
Community	Reach	Alternative A	Alternative B	Alternative C	Alternative A	Alternative B	Alternative C
Township of Abington	7	3	9	12	2	6	7
	8	3	9	12	2	6	7
	9	3	9	11	2	6	7
	31	2	6	10	1	3	5
	32	0	12	15	0	7	8
Borough of Bryn Athyn	11	3	8	11	2	4	6
	12	3	8	10	2	4	5
	13	3	8	10	1	4	5
	35	1	11	11	0	7	7
Borough of Hatboro	15	2	6	10	1	3	5
	16	2	5	9	1	2	5
	17	4	14	23	3	7	13
	47	13	33	37	5	14	14
	50	2	3	5	1	2	3
	51	2	3	5	1	2	3
	52	1	3	4	1	1	2
	53	1	1	3	0	1	1
Township of Horsham	17	4	14	23	3	7	13
	18	4	13	21	2	6	12
	19	4	13	21	2	6	12
	20	4	14	14	3	9	9
	48	10	24	29	7	16	19
	49	10	24	29	7	16	19
	50	2	3	5	1	2	3
	51	2	3	5	1	2	3
Township of Lower Moreland	9	3	9	11	2	6	7
	10	3	8	11	2	5	6
	11	3	8	11	2	4	6
	13	3	8	10	1	4	5
	33	0	13	17	0	8	10
	34	0	13	17	0	8	10
	35	1	11	11	0	7	7
	36	1	8	8	1	5	5
	37	7	10	11	4	5	6
	38	8	11	13	4	5	7
City of Philadelphia	1	1	8	13	0	4	7
	2	1	8	13	0	4	7
	3	3	10	13	2	6	7
	4	3	10	13	2	6	8
	5	3	9	12	2	6	8
	6	3	9	12	2	6	8
	7	3	9	12	2	6	7
	21	7	9	20	5	5	11
	22	11	13	28	6	7	15
	23	5	7	28	3	4	15
	24	5	8	22	3	4	13
	25	7	10	10	4	5	5
	26	5	5	36	3	3	20
	27	12	15	19	7	8	11
	28	17	21	24	10	13	14
	29	2	9	17	1	6	11
	30	7	32	34	4	19	20

Table 7 (cont.)

IMPACTS OF ALTERNATIVE FUTURE DEVELOPMENT PLANS ON RUNOFF

		% Increase in Runoff 10-Year Flood			% Increase in Runoff for 100-Year Flood		
Community	Reach	Alternative A	Alternative B	Alternative C	Alternative A	Alternative B	Alternative C
Township of Upper Moreland	11	3	8	11	2	4	6
	12	3	8	10	2	4	5
	13	3	8	10	1	4	5
	14	3	9	11	2	4	6
	15	2	6	10	1	3	5
	16	2	5	9	1	2	5
	17	4	14	23	3	7	13
	37	7	10	11	4	5	6
	38	8	11	13	4	5	7
	41	2	5	5	1	3	3
	42	2	3	3	1	2	2
	43	2	3	3	1	2	2
	44	1	9	14	0	5	7
	45	2	5	6	1	2	3
	46	3	6	6	2	4	4
	47	13	33	37	5	14	14
	48	10	24	29	7	16	19
	49	10	24	29	7	16	19
	50	2	3	5	1	2	3
	51	2	3	5	1	2	3
	52	1	3	4	1	1	2
Township of Upper Southampton	38	8	11	13	4	5	7
	39	3	4	5	2	2	3
	40	3	3	3	2	2	2
Township of Warminster	39	3	4	5	2	2	3
	40	3	3	3	2	2	2
	42	2	3	3	1	2	2
	43	2	3	3	1	2	2
	51	2	3	5	1	2	3
	53	1	1	3	0	1	1


LOCATION OF
SAMPLE
DAMAGE REACH
OLD WELSH ROAD
HUNTINGDON PIKE
232



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Philadelphia District, Corps of Engineers

PLATE 4

PENNYPACK WATERSHED

GRID CELL APPROXIMATION OF 100-YEAR FLOODPLAIN DELINEATION

SCALE IN FEET

400 0 400

SUMMARY OF RESULTS

TABLE 8				
HYDROLOGIC AND HYDRAULIC ANALYSIS				
	Existing Development	**Alternative A**	**Alternative B**	**Alternative C**
Land Use	• 64% urbanized (47% residential) • 36% undeveloped	• 70% urbanized (51% residential) • 30% undeveloped	• 82% urbanized (61% residential) • 18% undeveloped	• 88% urbanized (65% residential) • 12% undeveloped
100-Year Flood Flow and Flooded Area	• 14,300 cubic feet/sec.; 1868 acres flooded	• 1% increase in flow • 1% increase in acres flooded	• 4% increase in flow • 2.6% increase in acres flooded	• 7% increase in flow • 3.3% increase in acres flooded

FLOOD DAMAGE EVALUATION

General

Planners, developers, decision-makers and regulatory agencies at the local, state and Federal level have recognized the need to quantify the risks associated with floodplain development in economic terms, as well as in terms of flooding probability, depth and duration. Floodplain occupants and the general public have been made very much aware, either through personal experience or media reporting, of economic and human losses due to flooding in urban or urbanizing areas. Frequently, however, very little is known about potential future flood damages that may be brought about by unwise or unplanned development both on and off the flood plain. Many flood losses might have been prevented if the planners and decision-makers had known in advance the probable economic consequences of proposed land use plans and regulatory policies.

This pilot study provided a means to calculate flood damages that might be expected to occur under basic alternative land use plans, and also considered the effects of implementing alternative regulatory policies.

These land use plans and policies are conceptual. Therefore, the calculated flood damages presented, while reported in actual (1977) dollars, should be viewed as revealing *relative impacts* and comparisons of land use and policy alternatives on an economic (flood damage potential) basis. They are not absolute statements of flood damages that will occur in the future.

As previously discussed, this study employed newly developed computer techniques designed specifically to analyze urbanizing watersheds and provide dynamic evaluations of land use changes. Appropriate data, such as land use and ground evaluation, were automatically extracted from the data bank by the computer. The computer also utilized the results of the hydrologic and hydraulic modeling and other inputs, such as the stage vs. damage characteristics of each land use category. It also calculated flood damage potential for the full array of selected alternatives. The dollar-damage results of these analyses can then be used to evaluate the economic consequences or benefits of planned activities both on and off the floodplain.

Economic Analysis

The economic analysis used information extracted from the data bank for average annual and single-event flood damage assessment of identified alternative land use plans and policy assumptions. As previously discussed, the methods of analysis were consistent with traditional techniques, but the task of obtaining basin modeling data was automated so that large-scale relatively rapid analyses were possible.

The Damage Reach Stage-Damage Calculation (DAMCAL) computer program[16] was used to construct an elevation-damage relationship for each grid cell within the floodplain, based on its land use from the data bank, and also aggregated the individual cell damage functions to an index location within each designated damage reach. Plate 5 is a computer-plotted map that shows the 53 damage reaches that were identified, based on certain hydrologic and hydraulic factors, and flood damage potential.

Stage-discharge data (rating curves) from the hydraulic analysis were selected and assigned to each damage reach. Reference floods were also selected based on the hydraulic and flood damage characteristics of each damage reach. The reference flood was needed to index properly, by elevation, each individual grid cell to the index station (damage center) of a given reach so that the aggregation of damage data could be performed.

The aggregated damage data were then merged with hydrologic and hydraulic data through the use of the interface computer program ATODTA[14]. The HEC-1 computer program[7] then computed average annual and single-event flood damages for each damage reach by accessing and utilizing data developed by ATODTA.

In the following sections are narrative, tabular and graphic summaries of expected single-event (10-year and 100-year) and average annual flood damages for each of the Alternative Land Use Plans and Regulatory Policies. Calculated flood damages are presented for each of the nine municipalities occupying floodplain land in the study area. Expected flood damages are also summarized for the entire Pennypack Watershed.

Existing and Future Flood Damage Potential

Economic analysis of existing flood potential indicates that with a 10-year flood throughout the Pennypack Watershed, $5.4 million in flood damages could be expected. In a 100-year flood, $23 million in damages could be expected.

For existing conditions in the Pennypack Watershed, $2.3 million in average annual damages can be expected. The comparatively high level of single event and average annual damages in the watershed under existing conditions is indicative of the fact that approximately two-thirds (64%) of the watershed is already urbanized, with a significant amount of damageable land uses already located in flood prone areas.

In the absence of floodplain management or other regulatory policies, single event (10-year and 100-year floods) and potential average annual damages can be seen to increase dramatically over existing conditions. This trend toward increasing flood damage potential is attributable to the basic alternative land use plans representing moderately increasing levels of storm runoff from new development throughout the watershed, and more significantly, the location of new development in flood prone areas.

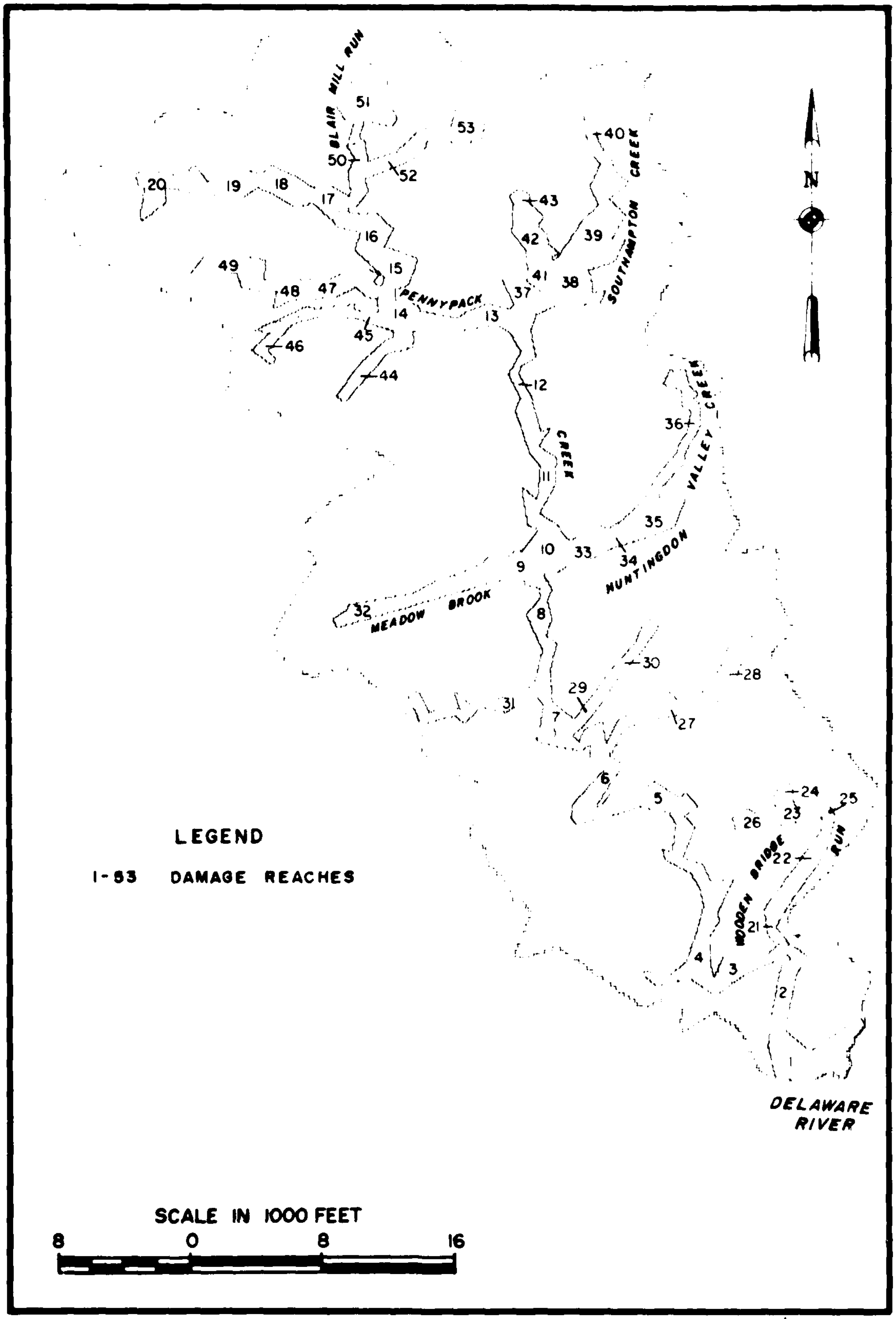


PLATE 5
DAMAGE REACHES

FLOODPLAIN REGULATORY POLICIES

General

If properly enacted and enforced, floodplain management regulations can be effective tools to reduce future flood hazard and flood damage potential. To provide local officials with an expanded set of alternatives from which to determine the implications of changing land use, the basic Alternative Land Use Plans (A, B and C) were further analyzed under five different assumptions of floodplain regulatory policies. These policies were selected to provide a more comprehensive assessment of future land use development both on and off the floodplain. They also demonstrate the flexibility and broad capabilities of the spatial analysis system and data management techniques used in this study.

Each alternative policy was applied, in turn, to each Alternative Land Use Plan to produce an array of possible conditions. These regulatory policies were selected and analyzed to demonstrate how various external constraints, applied to future development, could conceivably mitigate flood damage potential. The policies represent increasing levels of regulation by combining flood damage reduction measures to produce cumulative effects. Close examination of each individual policy assumption reveals the relative benefits to be gained by enacting and enforcing reasonable restrictions on further development.

FLOODPLAIN REGULATORY POLICIES

DEFINITIONS / SUMMARY OF EFFECTS

Policy 1 — No Restrictions

DEFINITIONS

No floodplain management regulatory constraints were placed on future development patterns under Policy 1. Future land uses under the Alternative Land Use Plans were allowed to be located within the floodplain up to the limits of a 2-year flood, without restrictions on first-floor elevations. The 2-year floodplain was adopted as a minimum standard for all floodplain regulatory policies. It was assumed that even in the absence of other constraints, future development would not occur in an area so prone to flooding and flood damage. In some areas the 2-year flood does not overtop the stream banks, and in these areas future development was allowed up to the stream embankment.

No provisions were made in this policy for the regulation of runoff effects created by new development. Although somewhat unrealistic, Policy 1 does provide a base condition for comparing the economic hazards of occupying flood-prone areas.

SUMMARY OF EFFECTS

Resultant flood damages indicate the relatively severe consequences of allowing totally unregulated development. Average annual damages expected under Alternative A Land Use Plan would be approximately $4.6 million, or twice that expected under existing conditions. Alternative B and C Land Use Plans would produce average annual damages of approximately $10.4 million and $23.5 million, respectively — representing flood damage potentials 4.5 and 10.0 times that which could be expected under existing conditions. Similar increases in 10-year and 100-year single event flood damages can be seen in Table 10 and Plates 7, 8, and 9.

Policy 2 — Runoff Restrictions

DEFINITIONS

Under this policy, future land uses were allowed to be located in the floodplain without restrictions on first-floor elevations, exactly as under Policy 1. However, the runoff associated with the new development both on and off the flood plain was assumed to be controlled to existing levels. This policy therefore simulated relatively unrestricted location or elevation of future development, but required that storm water retention or detention systems be used to control 100% of the increased runoff caused by new construction.

SUMMARY OF EFFECTS

Average annual flood damages can be seen to decrease only slightly under Alternative A as compared to Policy 1. However, adoption of this policy for Alternative B shows a 28% decrease in average annual damage over Policy 1. The greatest effect of controlling future runoff under Policy 2 can be seen for Alternative C for which average annual damages can be reduced by one-half, to $11.4 million. These results indicate that significant benefits can be achieved by maintaining runoff at existing levels, as development is otherwise allowed to increase unrestricted. However, substantial flood damage

Policy 2 — Runoff Restrictions

potential can still be expected under each Alternative Land Use Plan, ranging from 1.9 to 5.0 times existing damages. This would indicate that while generally beneficial, storm water retention or detention regulations alone will still leave the potential for high residual damages in the Pennypack Watershed, unless other regulatory measures are imposed.

Policy 3 — Floodway Restrictions

This alternative regulatory policy prohibited construction under future land use plans within the floodway limits, but allowed construction in the floodway fringe area provided that it was elevated to at least 1.0 foot above the existing 100-year flood elevation.

No provisions were made to control the increased runoff created by new construction. Therefore, future 100-year flood elevations may be above or below final fill or construction elevations established by a floodway under existing conditions. This regulatory policy generally simulated future development in the watershed being restricted in accordance with the minimum standards of the National Flood Insurance Program.

Economic analyses indicated that for this condition, average annual damages for each Alternative Land Use Plan would remain slightly above existing levels. These results would indicate that regulating new construction in floodway and flood fringe areas, similar to the minimum requirements of the National Flood Insurance Program, could be very effective in controlling future flood damage potential. Average annual damages could still be expected to range from 1.0 to only 1.3 times existing levels. These results indicate, when compared to the results under Policy 2, that there are substantially more benefits to be gained from regulating *where* and *how* new construction can take place, rather than only controlling the increased *runoff produced by more development.*

Policy 4 — Floodway Restrictions with Floodproofing

Under this regulatory policy, the same floodway and flood fringe restrictions were applied as under Policy 3. However, Policy 4 imposed an additional requirement of floodproofing the existing structures by permanent and/or temporary closures of openings. This requirement assumes a uniform level of protection within each damage reach. The level of protection varied between 1 to 3 feet depending upon the physical attributes of structures within a damage reach and flood flow and elevation characteristics were also taken into consideration. In general the protection afforded was below a 10 year flood level.

It is important to note here that floodproofing was conceptually applied to existing structures in the floodplain without regard to site-specific engineering feasibility. A detailed engineering analysis would have to be performed on each structure to determine whether floodproofing could be safely and effectively applied.

For Alternative A and B Land Use Plans, average annual damages *decreased* slightly to $1.9 and $2.2 million respectively, or to approximately 80% and 90% of existing average annual damages. The addition of floodproofing requirements for existing floodplain development would result in 20% and 30% decreases in average annual damages over Policy 3 requirements covering only new construction. For the Alternative C Land Use Plan, average annual damages would be held to only a 10% increase over existing conditions.

Policy 5 — Floodway, Floodproofing and Runoff Restrictions

This regulatory policy assumed the same floodway, flood fringe and floodproofing constraints as under Policy 4, with additional constraints on new development to maintain surface runoff at existing

Application of Policy 5 to the Alternative A Land Use Plan would reduce average annual damages to 30% below existing levels. Similar reductions of 20% and 10% could be expected for the Alternative B and

Policy 5 — Floodway, Floodproofing, and Runoff Restrictions

levels. This policy therefore represented an intense effort to mitigate flood hazards and flood damages by: (1) restricting the location and elevation of new construction in floodplain areas to prevent or minimize future damages; (2) by floodproofing to mitigate damage to existing structures; (3) restricting runoff to prevent increased flood hazards and flood damages caused by future development outside the flood plain.

C Land Use Plans. Similarly, 10-year and 100-year single event flood damages would be maintained at or just slightly above those that could be expected under existing densities and patterns of development.

Flood Damage Evaluation

Table 9 shows damage to the entire watershed, using Policy 1 only for all five regulatory policies.

Plates 6-9 graphically illustrate the potential flood damage that might be expected to occur in the watershed under Existing and Alternative Future Land Use Plans, and demonstrate the relative effectiveness of each Regulatory Policy on mitigating damage potential.

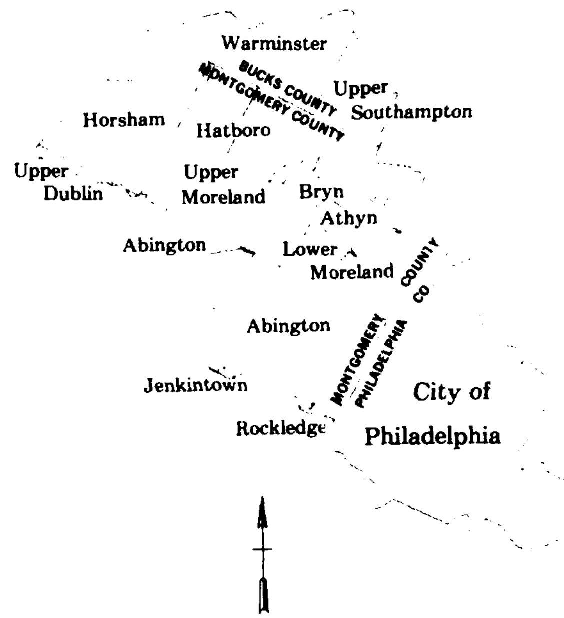
Comparisons of the flood damages presented by each municipality with those presented for the watershed as a whole will reveal in which communities the majority of flood damages could be expected to occur and what effect each regulatory policy might have on reducing flood damages in these communities. Table 10 summarizes the 10-year, 100-year and average annual damages that could be expected to occur in each of nine municipalities occupying floodplain land in the watershed. Table 11 summarizes 100-year and average annual damages by land use categories and communities.

The predictions are clear. With uncontrolled development, future flood damage could be much more severe than anything experienced or even predicted heretofore. But prompt and prudent planning and action can control future development and hold future flood damage below, or at worst slightly above, present levels.

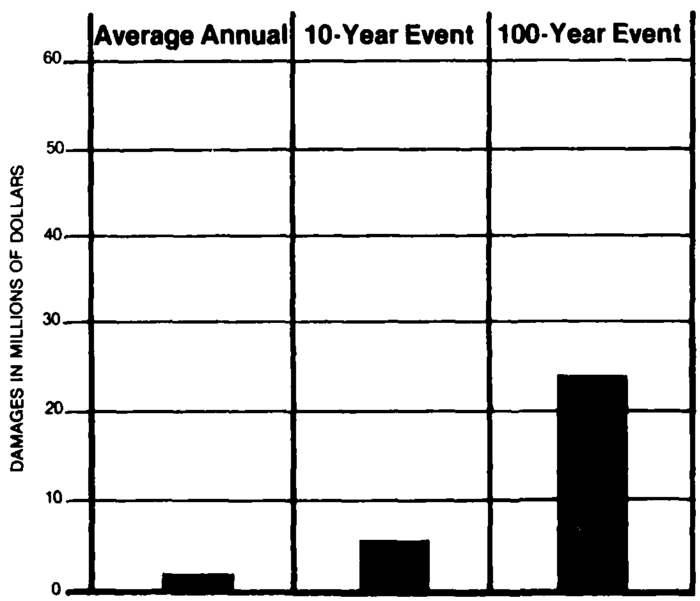
TABLE 9

SUMMARY OF DAMAGES
Whole Watershed — Policy 1 Only

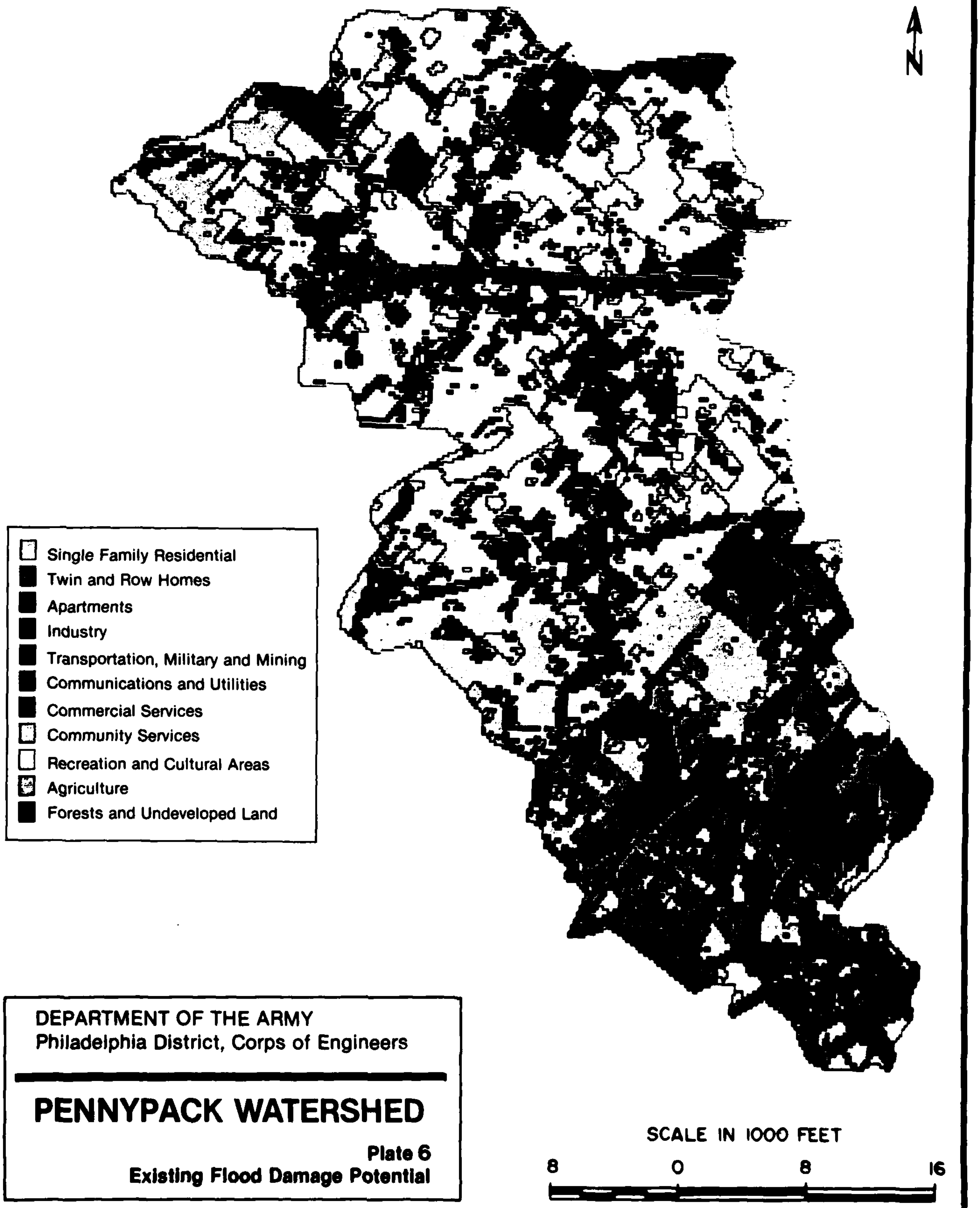
	Existing	Alternative A	Alternative B	Alternative C
	Damages (x $1,000)			
[illegible]	[illegible]	30,000	21,000	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2,700	4,700	10,400	[illegible]



Existing Land Use



EXISTING FLOOD DAMAGE POTENTIAL



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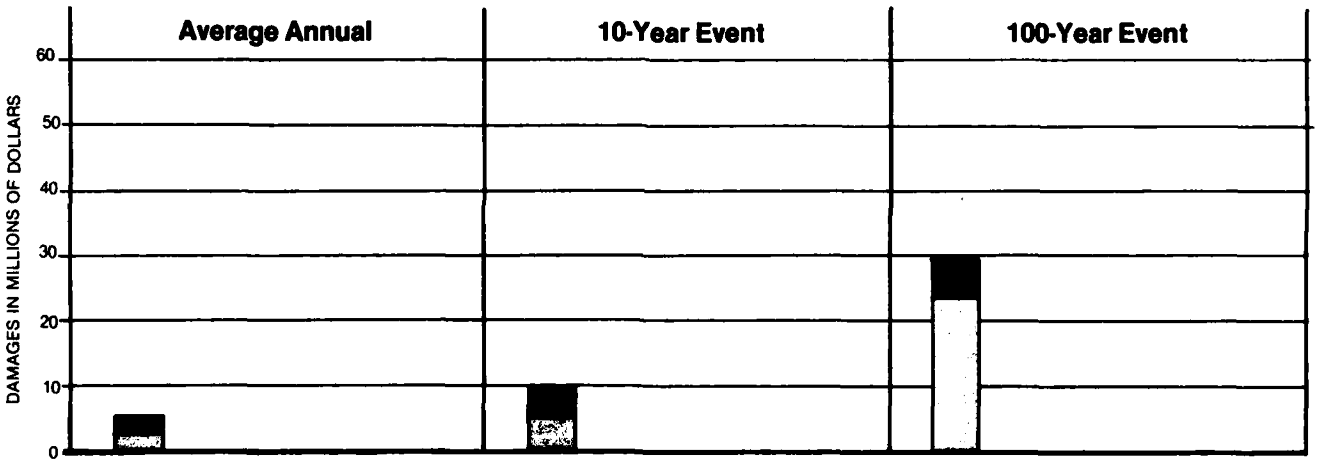
PENNYPACK WATERSHED

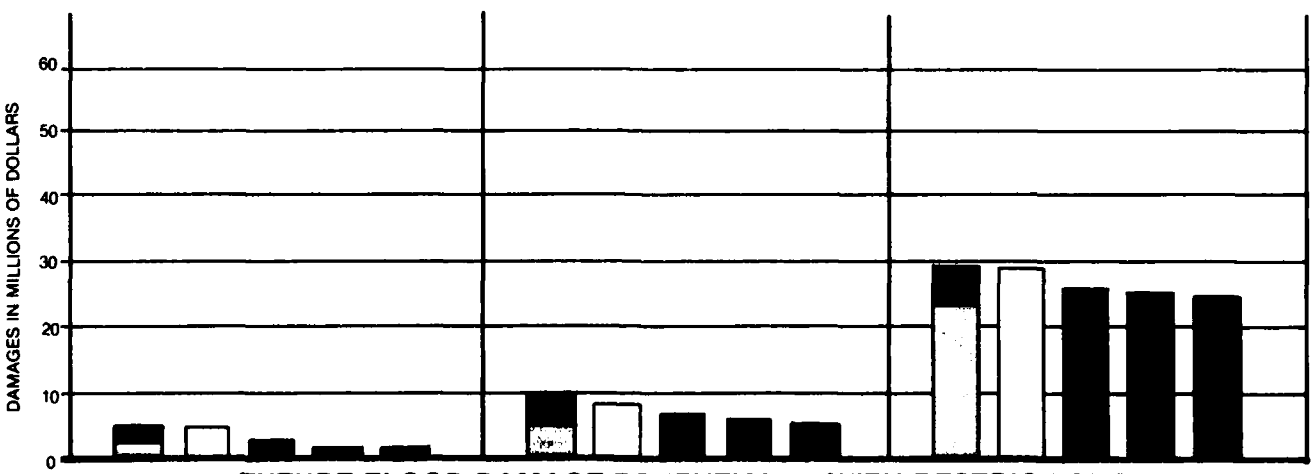
Plate 6
Existing Flood Damage Potential

Alternative A Plus Five Policies

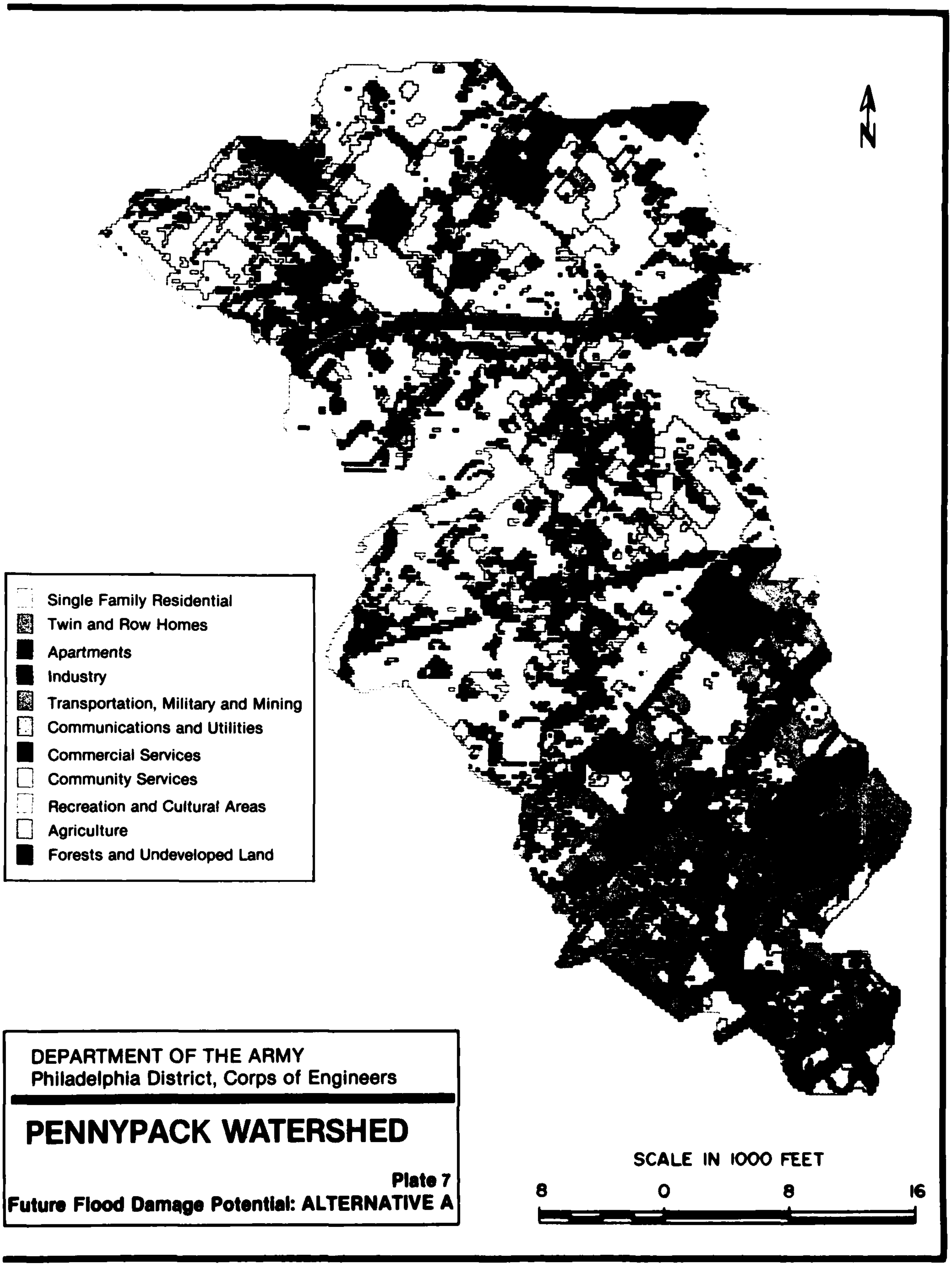
Policy 1	No restrictions.	
Policy 2	Runoff maintained at existing levels.	
Policy 3	Floodway Restrictions (similar to National Flood Insurance Program).	
Policy 4	Floodway Restrictions with Floodproofing.	
Policy 5	Combination of Policy 2 and Policy 4.	
Existing conditions.		



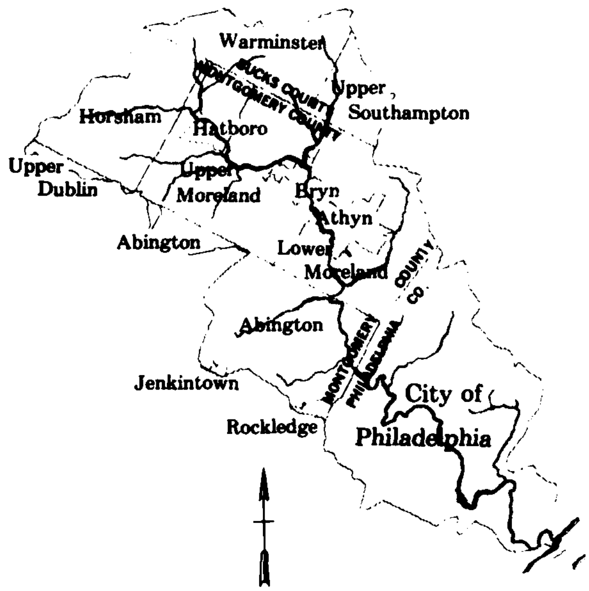
FUTURE FLOOD DAMAGE POTENTIAL — NO RESTRICTIONS (Policy 1)



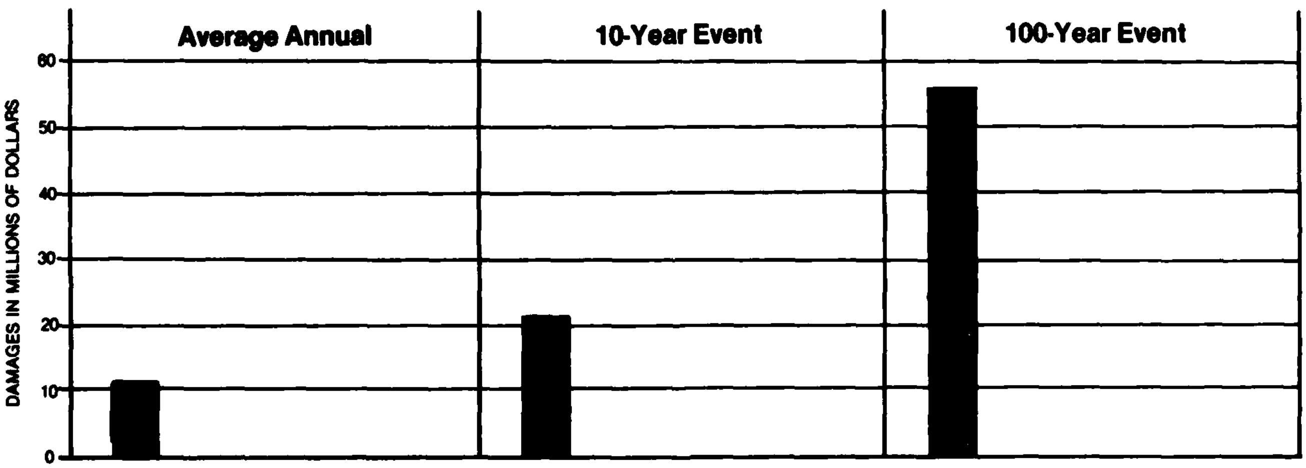
FUTURE FLOOD DAMAGE POTENTIAL — WITH RESTRICTIONS


N
Single Family Residential
Twin and Row Homes
Apartments
Industry
Transportation, Military and Mining
Communications and Utilities
Commercial Services
Community Services
Recreation and Cultural Areas
Agriculture
Forests and Undeveloped Land
DEPARTMENT OF THE ARMY
Philadelphia District, Corps of Engineers
PENNYPACK WATERSHED
Plate 7
Future Flood Damage Potential: ALTERNATIVE A
SCALE IN 1000 FEET
8
0
8
16

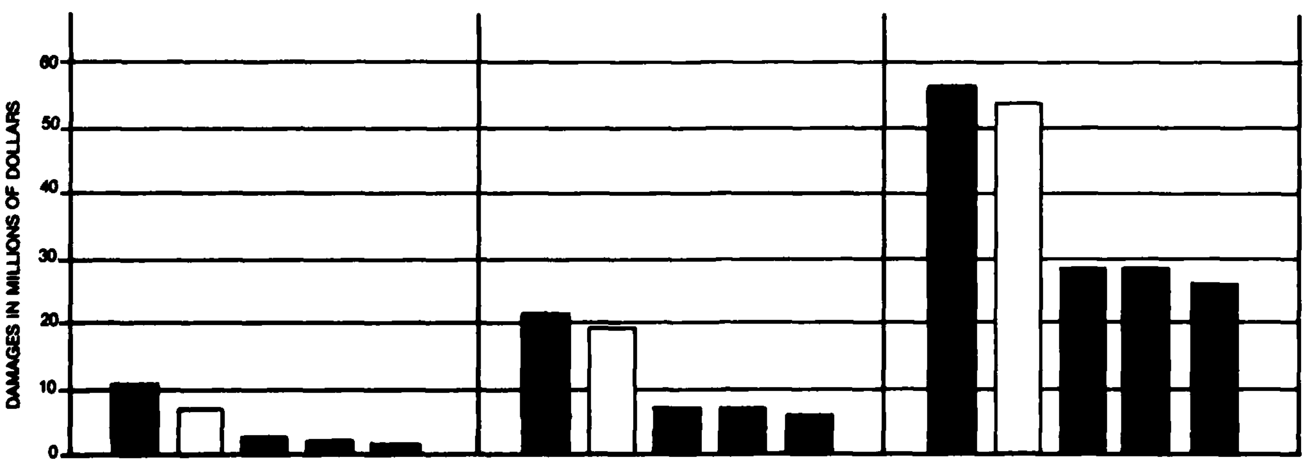
Alternative B Plus Five Policies



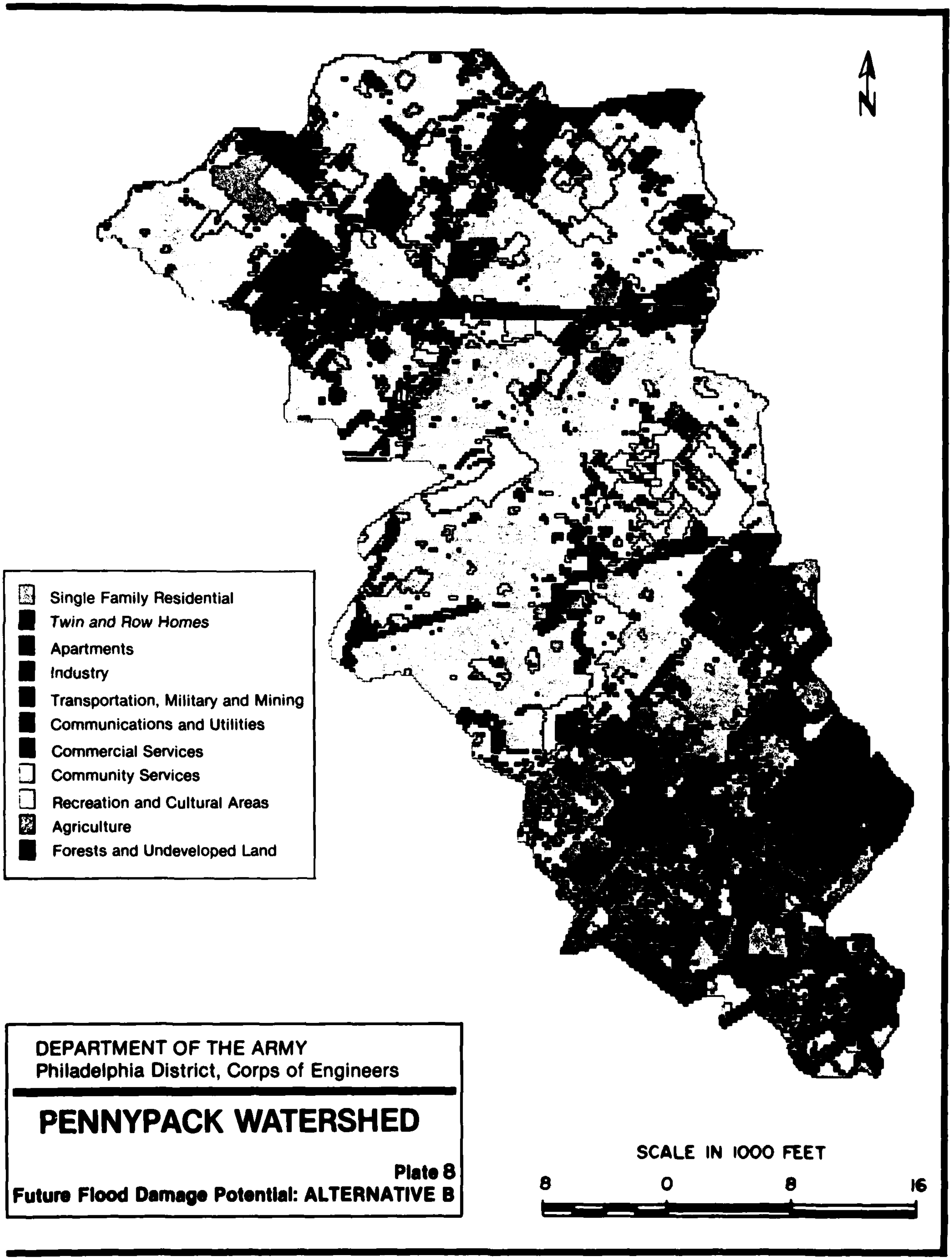
Policy 1	No restrictions.	
Policy 2	Runoff maintained at existing levels.	
Policy 3	Floodway Restrictions (similar to National Flood Insurance Program).	
Policy 4	Floodway Restrictions with Floodproofing.	
Policy 5	Combination of Policy 2 and Policy 4.	
Existing conditions.		



FUTURE FLOOD DAMAGE POTENTIAL — NO RESTRICTIONS (Policy 1)



FUTURE FLOOD DAMAGE POTENTIAL — WITH RESTRICTIONS



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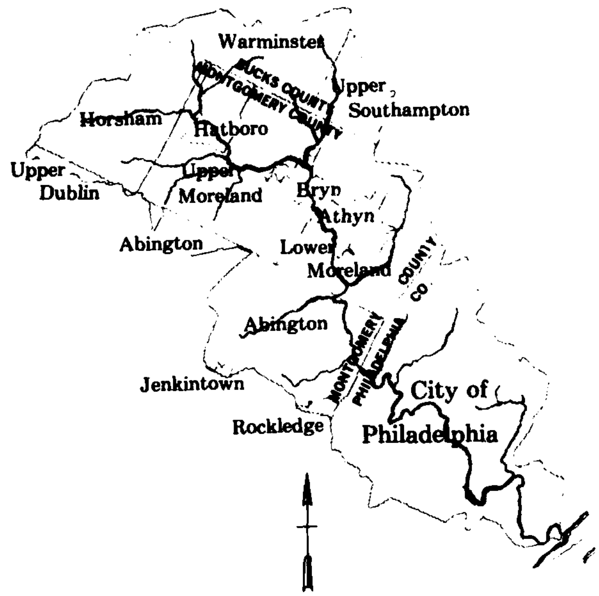
PENNYPACK WATERSHED

Plate 8
Future Flood Damage Potential: ALTERNATIVE B

Alternative C Plus Five Policies



Policy 1 No restrictions.

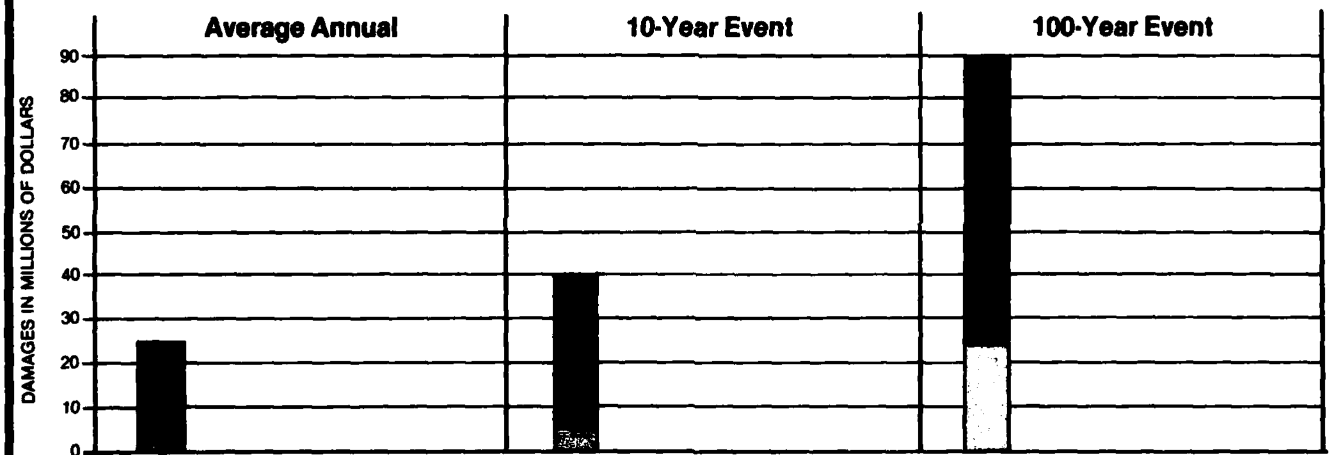
Policy 2 Runoff maintained at existing levels.

Policy 3 Floodway Restrictions (similar to National Flood Insurance Program).

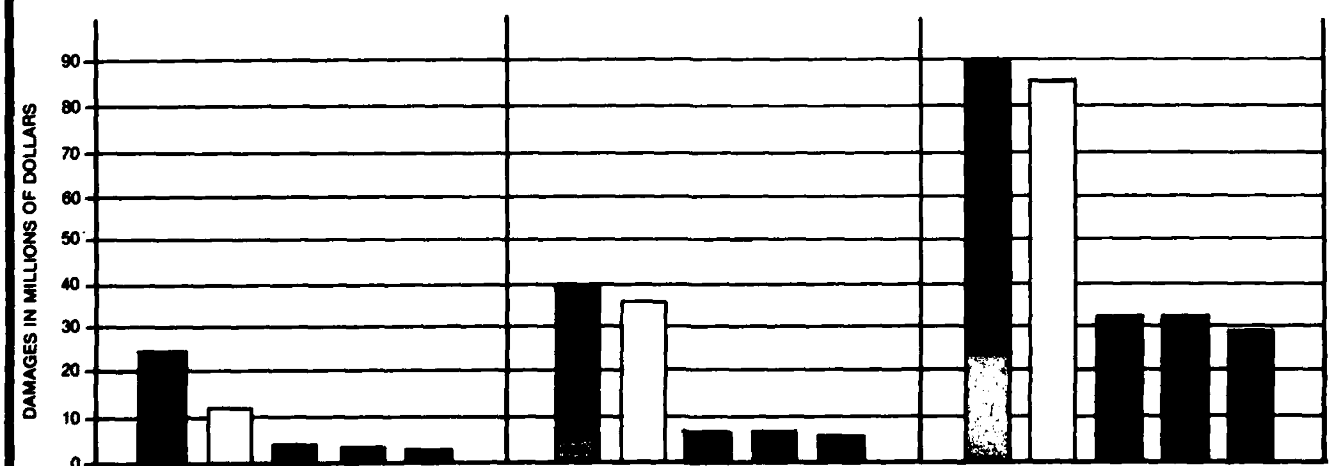
Policy 4 Floodway Restrictions with Floodproofing.

Policy 5 Combination of Policy 2 and Policy 4.

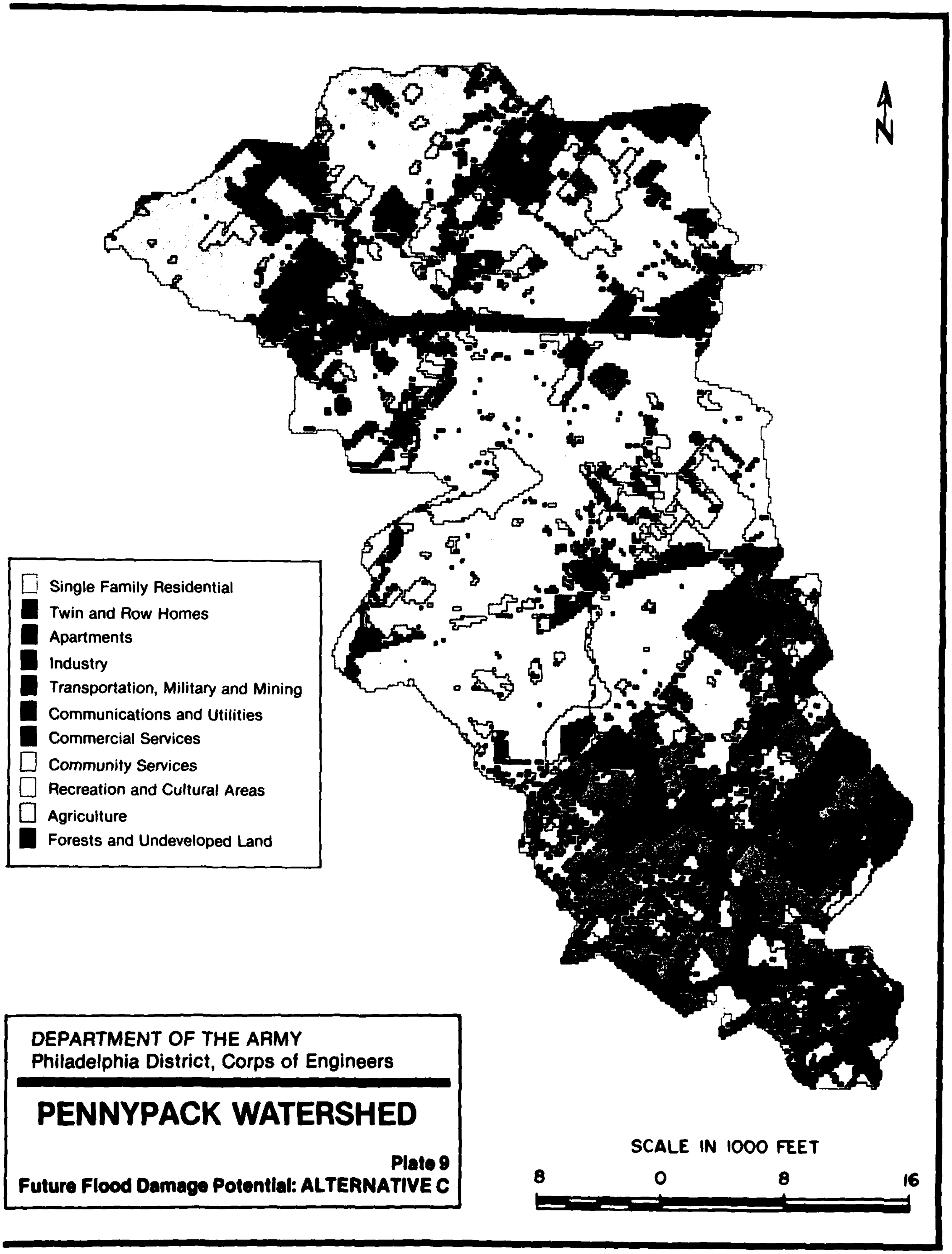
Existing conditions.



FUTURE FLOOD DAMAGE POTENTIAL — NO RESTRICTIONS (Policy 1)



FUTURE FLOOD DAMAGE POTENTIAL — WITH RESTRICTIONS


N
Single Family Residential
Twin and Row Homes
Apartments
Industry
Transportation, Military and Mining
Communications and Utilities
Commercial Services
Community Services
Recreation and Cultural Areas
Agriculture
Forests and Undeveloped Land
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Philadelphia District, Corps of Engineers
PENNYPACK WATERSHED
Plate 9
Future Flood Damage Potential: ALTERNATIVE C
SCALE IN 1000 FEET
8
0
8
16

TABLE 10

SUMMARY OF FLOOD PLAIN REGULATORY POLICIES ON FLOOD DAMAGE POTENTIAL — BY COMMUNITIES

DAMAGE ($1000)		REGULATORY POLICY	ABINGTON	BRYN ATHYN	HATBORO	HORSHAM	LOWER MORELAND	PHILADELPHIA	UPPER MORELAND	UPPER SOUTHAMPTON	WARMINSTER
EXISTING	10-YR. EVENT		$ 410	$ 40	$ 830	$ 180	$1,380	$1,020	$ 800	$ 440	$ 330
	100-YR. EVENT		1180	160	2,900	650	7,320	5,300	3,350	1,150	1,070
	AVERAGE ANNUAL		180	20	340	80	570	500	370	160	140
ALTERNATIVE A	10-YR. EVENT	1	1,080	90	1,310	440	2,100	1,950	1,980	650	450
		2	1,060	80	1,280	420	1,380	1,840	1,880	880	440
		3	440	60	940	200	1,570	1,180	950	480	350
		4	420	50	940	170	1,570	1,120	800	480	280
		5	420	60	910	160	1,500	1,010	680	470	280
	100-YR. EVENT	1	1,980	280	3,380	1,030	7,880	7,050	5,380	1,380	1,210
		2	1,980	280	3,380	1,000	7,280	6,870	5,240	1,930	1,200
		3	1,270	230	2,980	700	7,980	6,140	3,730	1,170	1,080
		4	1,270	230	2,980	700	7,980	6,140	3,730	1,170	1,080
		5	1,280	230	2,930	670	7,910	5,980	3,550	1,160	1,070
	AVERAGE ANNUAL	1	610	40	570	230	600	1,070	980	370	190
		2	610	40	580	220	590	1,010	930	360	190
		3	180	20	280	80	590	560	410	170	140
		4	120	20	280	80	520	460	270	120	90
		5	120	10	270	50	500	410	240	120	80
ALTERNATIVE B	10-YR. EVENT	1	1,800	2,500	1,370	600	5,560	2,160	5,540	980	520
		2	1,620	2,340	1,290	540	4,860	1,920	5,100	940	510
		3	500	50	990	220	1,940	1,270	1,070	490	350
		4	480	50	980	200	1,930	1,220	970	490	290
		5	420	40	910	160	1,500	1,000	680	470	280
	100-YR. EVENT	1	5,250	5,660	3,440	1,600	15,710	7,790	12,840	2,030	1,310
		2	4,990	5,500	3,400	1,410	15,000	7,330	12,270	2,000	1,300
		3	1,920	460	3,010	780	9,180	6,430	4,120	1,220	1,080
		4	1,920	460	3,010	780	9,180	6,430	4,110	1,220	1,080
		5	1,670	420	2,960	680	8,410	6,000	3,730	1,200	1,070
	AVERAGE ANNUAL	1	990	1,320	600	330	2,270	1,380	2,890	400	240
		2	900	510	580	290	1,860	1,220	2,430	380	230
		3	230	30	300	90	720	650	470	180	140
		4	170	20	290	70	640	550	320	130	90
		5	140	20	270	50	510	450	250	120	80
ALTERNATIVE C	10-YR. EVENT	1	2,880	5,870	1,710	1,340	13,830	3,430	9,420	1,010	530
		2	2,430	5,410	1,580	980	13,180	2,780	8,520	970	520
		3	500	50	1,030	240	1,920	1,380	1,080	490	340
		4	480	50	1,030	220	1,920	1,380	980	480	280
		5	410	40	900	170	1,520	1,020	670	470	270
	100-YR. EVENT	1	6,170	11,700	4,380	2,440	28,680	11,880	20,880	2,120	1,340
		2	5,880	11,380	4,280	2,180	27,800	10,870	19,880	2,080	1,330
		3	2,220	630	3,040	880	11,380	7,080	4,540	1,220	1,080
		4	2,220	630	3,040	840	11,380	7,080	4,540	1,220	1,080
		5	1,820	600	2,840	720	10,010	6,270	3,880	1,200	1,080
	AVERAGE ANNUAL	1	1,480	3,270	780	600	9,580	2,180	5,000	410	280
		2	1,310	1,340	700	510	2,080	1,730	3,210	380	240
		3	240	30	320	110	810	720	480	180	130
		4	180	30	320	80	730	620	340	130	80
		5	140	30	270	80	580	470	280	120	80

*1. No Restrictions
2. Runoff Restrictions
3. Floodway Restrictions
4. Floodway Restrictions with Floodproofing
5. Combination of Policies 2 and 4

TABLE 11

SUMMARY OF FLOOD DAMAGE POTENTIAL BY LAND USE CATEGORIES AND COMMUNITIES (Policy 1)

DAMAGE ($1000)		AGGREGATED LAND USE CATEGORY*	ABINGTON	BRYN ATHYN	HATBORO	HORSHAM	LOWER MORELAND	PHILADELPHIA	UPPER MORELAND	UPPER SOUTHAMPTON	WARMINSTER
EXISTING	100-YEAR EVENT	1	344	154	425	310	908	615	1336	1111	443
		2	0	0	77	0	0	308	0	36	0
		3	156	0	60	38	236	278	186	0	225
		4	156	0	76	71	3354	69	945	0	2
		5	234	0	247	202	2688	210	616	0	223
		6	288	0	2013	24	116	3813	253	0	178
		7	8	3	0	1	18	4	17	2	0
	AVERAGE ANNUAL	1	40	16	57	37	77	74	153	161	56
		2	0	0	10	0	0	38	0	4	0
		3	22	0	7	5	22	29	17	0	29
		4	12	0	3	3	268	6	105	0	0
		5	36	0	22	27	190	16	68	0	25
		6	67	0	238	4	7	336	24	0	27
		7	1	1	0	0	2	1	2	0	0
ALTERNATIVE A	100-YEAR EVENT	1	558	280	487	483	1278	685	1902	1128	477
		2	0	0	106	9	0	599	25	38	0
		3	208	0	64	57	265	502	235	0	251
		4	245	0	78	126	3384	73	1931	310	2
		5	228	8	255	321	3013	272	954	0	282
		6	727	0	2413	32	130	4917	310	0	198
		7	14	3	0	1	18	5	22	2	3
	AVERAGE ANNUAL	1	107	39	82	102	166	88	320	251	71
		2	0	0	19	1	0	167	1	4	0
		3	39	0	8	16	23	148	38	0	36
		4	62	0	3	6	159	7	325	112	0
		5	38	1	23	100	247	37	246	0	51
		6	368	0	436	9	7	620	50	0	36
		7	1	1	0	0	2	2	4	0	1
ALTERNATIVE B	100-YEAR EVENT	1	3759	2655	470	599	3777	812	5202	1988	574
		2	0	0	105	99	0	771	2617	38	0
		3	229	0	99	158	339	663	244	0	251
		4	266	0	78	377	4183	73	3255	0	2
		5	239	2531	282	333	5759	284	1216	0	282
		6	748	470	2400	32	1485	5262	287	0	198
		7	12	3	1	1	169	6	17	2	3
	AVERAGE ANNUAL	1	449	653	85	141	608	106	1247	390	115
		2	0	0	19	14	0	189	412	4	0
		3	47	0	12	38	35	363	41	0	36
		4	68	0	3	23	453	8	889	0	0
		5	43	589	29	105	916	38	324	0	51
		6	387	73	449	9	123	677	70	0	36
		7	1	1	0	0	40	2	2	0	1
ALTERNATIVE C	100-YEAR EVENT	1	4803	3030	1273	1160	3626	1128	10886	2054	804
		2	0	0	108	328	0	2790	0	38	0
		3	401	0	64	82	352	707	239	0	255
		4	245	7217	120	343	21286	1598	4677	0	2
		5	241	0	319	482	3061	427	4822	24	277
		6	680	1441	2480	32	296	5227	277	0	202
		7	14	3	1	1	18	5	21	2	3
	AVERAGE ANNUAL	1	874	686	234	311	887	171	2367	387	119
		2	0	0	20	60	0	636	0	4	0
		3	100	0	8	18	41	380	42	0	37
		4	60	2186	11	22	8637	201	943	0	0
		5	44	0	32	180	287	62	1586	7	51
		6	380	801	486	9	78	681	71	0	36
		7	1	1	0	0	0	2	5	0	1

*1 Low Density Residential
2 Med. Density Residential
3 High Density Residential
4 Industrial
5 Commercial
6 Community Services
7 Other (Trans., Utilities, etc.)

ENVIRONMENTAL EVALUATION

General

In addition to recognizing the flood hazard and flood damage potentials associated with future development, planning agencies and the public are becoming increasingly sensitive to environmental implications. An ever-broadening range of concerns is being addressed in order to balance the need for future growth and expansion against the need to protect and preserve qualities such as natural habitats, air and water quality, and other important natural resources.

Environmental concerns, in general land use and comprehensive planning can be addressed initially by identifying the broad implications of land use change on the environment. This study attempted to meet this initial need by identifying the relative impact of increased urbanization on natural habitats and water quality in the watershed. These relative impacts were keyed to changes in land use projected under future land use schemes.

Habitat

The Pennypack Watershed is generally not an environmentally or ecologically unique area. Its environmental character is fairly typical of similar predominantly urbanized watersheds in the north-eastern United States.

Approximately two-thirds of the watershed is urbanized under existing conditions. Several large tracts of land, including Pennypack Park in the City of Philadelphia, Lorimar Park in Abington and the Wilderness Park of the Pennypack Watershed Association, have preserved floodplain and adjacent land for passive recreational activities and natural habitat areas for various species of plants and animals. Many smaller, undeveloped tracts of land are scattered throughout the watershed, and have varying environmental qualities related to their size, physical characteristics and relationships to adjoining developed or undeveloped areas. Some smaller tracts are completely surrounded by medium to high density urban development which significantly detracts from their inherent quality as natural habitats. The lack of ecotone or "buffer" zones between developed and undeveloped areas limits their ability to support stable populations of wildlife. However, these areas may still be important for their storm water infiltration, floodflow storage, and aesthetic or recreational qualities. The overall environmental quality of an undeveloped area may be significantly greater than its intrinsic value if it is the only remaining "natural" tract of land in an otherwise fully developed area.

There are no threatened or endangered species in the watershed, but the forecast increases in urbanization would cause even greater losses of natural habitat than have already occurred. Each scheme of projected future land use analyzed in this study represented increasing urbanization with corresponding decreases in undeveloped land to support natural vegetation and wildlife. Other natural functions such as storm water infiltration, groundwater recharge and, in the case of floodplain areas, flood flow storage would also be affected.

While it is not the intent of this study to provide precise inventories of plant and animal species in the Pennypack Watershed, a general examination of vegetation can provide some insight into the types, diversity, and quality of wildlife habitat that might be found. With this information, land use managers can make more informed decisions regarding the relative environmental or ecological impacts of changing land use.

Eleven basic habitat types were delineated for this study. Each is distinguished by a predominant type of vegetation found there. Vegetation differs with land use, ranging from old fields in early stages of succession to mature stands of hardwoods. Old fields, once cultivated farmland, may be sparsely to heavily covered with weedy, herbaceous species and in time may be invaded by woody species. Landscaped areas consist primarily of turf grasses, shrubs, and ornamental and shade trees. Each vegetation type is important for its ability to support wildlife.

A mixture of habitat types may be preferable to a single type for many species in this area. For example, a hardwood forest surrounded by an old field or a fresh water marsh may support more diverse and healthier wildlife than might be expected when considering these habitats separately.

For some species of wildlife, a particular habitat type must cover a minimum area in order to support a healthy population. For example, a few dozen square yards of open field might support a population of field mice, but several acres of old field are required to support a pair of hawks or owls. Likewise, a deer might range over 40-50 acres of woodland during normal foraging, while a muskrat requires only a few acres of marsh to survive.

Eleven Basic Habitat Types

Mature hardwood forests and *mixed hardwood-conifer forests* usually have an overstory of red and white oaks, some beech and maple trees, and various conifers. Some hickory and black walnut can also be found. The understory consists mainly of young hardwoods: maples, dogwoods, oaks and beeches. The ground cover usually consists of viburnums, ferns and low shrubs. (Each level of vegetation contains its own assemblage of species.) On the ground, the eastern box turtle, some snake species, and mammals such as the white-tailed deer, red fox and masked shrew can be found. Few bird species nest on the ground in the open woods. The understory and canopy, on the other hand, provide shelter for a variety of bird species such as the great horned owl, red-tailed hawk and common flicker, along with woodpeckers, titmice and nuthatches, to name a few. Certain arboreal mammals can also be found: the gray squirrel, red bat and opossum.

Medium hardwood forests, with their less dense understory growth, show similar species. In addition to the species found in the young hardwood forest, the white-tailed deer, red fox and gray squirrel are found occasionally. Birds are still present, including the gray catbird, wood thrush, ruby-throated hummingbird, finch, warbler and sparrow.

Young hardwood forests usually contain a mixture of open field and forest species. Small mammals, like the meadow vole and white-footed mouse, and larger mammals, like the eastern cotton-tail and striped skunk, are fairly common. Birds which like dense growth, such as the red-eyed towhee, wood thrust and gray catbird are here.

Mixed forests contain both hardwoods and conifers. In typical mixed forest, 50% or more of the trees are oaks. The other dominant canopy species are pines. Dominant understory species include younger oaks and pines, sassafras, laurel, blueberry and huckleberry. Gound cover may be sparse, consisting mainly of ferns, wintergreen bearberry and low shrubs. Common amphibians and reptiles of the pine-oak forest include the northern fence lizard, marbled salamander, Fowler's toad, eastern box turtle, midland brown snake, eastern hognose snake and eastern garter snake. Bird species include the turkey, vulture, red-shouldered hawk, downy woodpecker, Carolina chickadee, blackbilled cuckoo, whippoor-will, great-crested flycatcher, red-eyed vireo, black and white warbler, pine warbler, ovenbird, American redstart, brown creeper, golden crowned kinglet and ruby-crowned kinglet. Mammal species include the pine vole, eastern chipmunk, eastern mole, New England cottontail, opossum, shorttail shrew, eastern cottontail, eastern gray squirrel, red squirrel, white-footed mouse, red fox, raccoon, skunk, white-tailed deer and brown bat.

Freshwater marshes might support wild rice, reed grass, cattails, bullrushes, arrowweed, pickerelweed, sedges and swamp rose. Mammal species include the opossum, white-tailed deer, rice rat, raccoon, striped skunk, eastern cottontail, muskrat, meadow vole and masked shrew, with an occasional red fox or weasel. Reptile and amphibian species include the southern leopard frog, common snapping turtle and eastern mud turtle. Bird species include the great blue heron, black-crowned night heron, black duck, marsh hawk, herring gull, horned grebe, great egret, snowy egret, glossy ibis, osprey, willet, black skimmer, long-billed marsh wren, Canada goose, American widgeon, greater yellowlegs, dunlin, Bonapart's gull, green-winged teal, ruddy turnstone, common snipe, semipalmated sandpiper, clapper rail and seaside sparrow.

Abandoned fields are composed mainly of herbaceous weed species such as foxtail, ragweed, wild mustard, milkweed, ironweed, bull thistle, blackberry, barberry and multiflora rose. Some young trees may also be present, for example; cherry, ash and willow. Abandoned fields usually support small mammal populations of meadow voles or house mice and possibly some rabbits and raccoons. Some ground nesting birds, such as the bobwhite quail, and some predatory birds like the screech owl or barn owl can also be found.

Tilled fields that support farm crops usually also support populations of the meadow vole, masked shrew, raccoon, striped skunk and opossum, and ground birds such as the ring-necked pheasant, killdeer and mourning dove. Other birds often in tilled fields are the crow, red-winged blackbird, screech owl, boat-tailed grackle and cowbird.

Maintained fields are mowed or plowed about once a year. They usually have a cover of clover or other fallow crop, or are cut for hay. A maintained field contains species similar to the cultivated field, but since it is disturbed less frequently it usually supports slightly more diverse bird and mammal populations such as wrens, warblers, sparrows and swallows, as well as ground nesting birds, an occasional hawk, and sometimes a red fox, striped skunk or opossum.

Mowed fields are grasslands that are periodically harvested. Where short growth is maintained, there is little cover for larger birds and mammals. The meadow vole, house mouse and mole can survive here, as can blackbirds, sparrows, starlings and domestic animals.

Non-urban landscaped areas usually contain ornamental trees, shrubs and open grassy areas, and so provide a variety of sheltered habitats for animals commonly found in mowed fields as well as some associated with hardwood forests. Many of the birds that appear on suburban bird feeders can be found here: finch, blue jay, robin, nuthatch, grossbeak, cardinal, etc. Actual wildlife is rare because of the artificial nature of the habitat, but the ever-present meadow vole and rabbit can survive well.

Urban areas provide a habitat for those species that can survive in close proximity to civilization. Those frequently seen include the house mouse, and Norway rat, pigeon, chimney swift and starling.

The above descriptions are by no means all-inclusive, and should serve to give only an overview of the various habitat types described. There is usually a measure of overlap between different habitat types, and wildlife assemblages are not always unique for each type.

Table 12 cross-references various species of wildlife common to the area, with the habitats in which they are most likely to be found. Examination of this information is useful in assessing the impact on wildlife directly or indirectly caused by changing land use. Plate 10 illustrates the geographical mix and extent of the eleven basic habitat types based on existing land use conditions. Table 13 summarizes approximate acreages of each existing habitat and, by comparison, the extent of those expected to remain under the Alternative C land use plan, which represents the greatest density of future development in the watershed.

The general information presented here can form the basis for interim decisions and a framework for future study. As more environmental data become available, more informed decisions can be made about the importance and environmental quality of individual land parcels and habitat areas.

Table 12

NATURAL HABITATS AND SPECIES

SPECIES	HABITAT											
	Urban Area	Hardwood Young	Hardwood Medium	Hardwood Mature	Mixed Forest Med.	Mixed Forest Mat.	Marsh	Abandoned Field	Tilled Filled	Maintained Field	Mowed Field	Non-Urban Landscaped
Common *(Scientific)*												
AMPHIBIANS/REPTILES												
Common Snapping Turtle *(Chelydra Serpentina)*							X					
Diamondback Terrapin *(Malaclemys Terrapin)*							X					
Eastern Box Turtle *(Terrapene Carolina)*				X	X							
Eastern Hognose Snake *Heterodon Platyrhinos)*				X	X							
Eastern Mud Turtle *(Kinosternon Subrubrum)*							X					
Fowler's Toad *(Bufo Woodhousei)*					X							
Marbled Salamander *(Ambystoma Opacum)*					X							
Midland Brown Snake *(Thamnphis Sirtalis)*				X	X							
Northern Fence Lizard *(Sceloporus Undulatus)*					X							
Southern Leopard Frog *(Rana Ultricularia)*							X					
BIRDS												
American Redstart *(Setophaga Ruticilla)*					X							
American Widgeon *(Mareca Americana)*							X					
Barn Owl *(Tuto Alba)*								X				
Black and White Warbler *(Mniotilta Varia)*					X							
Black-Biled Cuckoo *(Coccyzus Erthropthalmus)*					X							
Black-Crowned Night Heron *(Nycticorax Nycticorax)*							X					
Black Duck *(Anas Rubripes)*							X					
Black Skimmer *(Rynchops Nigra)*							X					
Blue Jay *(Cyanocitta Cristata)*												X
Bat-Tailed Grackle *(Cassidix Mexicanus)*									X			
Bobwhite Quail *(Colinus Virginianus)*								X				
Bonaparte's Gull *(Larus Philadelphia)*							X					
Brown Creeper *(Lerthia Familiaris)*					X							
Canada Goose *(Branta Canadensis)*							X					
Cardinal *(Cardinalis Cardinalis)*												X
Carolina Chickadee *(Parus Carolinensis)*					X							
Chimney Swift *(Chaetura Pelogica)*	X											
Clapper Rail *(Rallus Longirostris)*							X					

Table 12

NATURAL HABITATS AND SPECIES

SPECIES	HABITAT											
	Urban Area	Hardwood Young	Hardwood Medium	Hardwood Mature	Mixed Forest Med.	Mixed Forest Mat.	Marsh	Abandoned Field	Tilled Filled	Maintained Field	Mowed Field	Non-Urban Landscaped
Common **(*Scientific*)**												
BIRDS												
Common Crow *(Corviva Brachyrhynchos)*									X			
Common Flicker *(Colaptes Auratus)*				X								
Common Shipe *(Capella Gallinago)*							X					
Cowbird *(Molothrus Ater)*									X			
Downy Woodpecker *(Dendrolopos Pubescens)*					X							
Dunlin *(Erolia Alpina)*							X					
Finches and Sparrows *(Family Fringillidae)*			X							X	X	X
Glossy Ibis *(Plegadis Falcinellas)*							X					
Golden-Crowned Ringlet *(Regulus Satrapa)*					X							
Catbird *(Dumeteua Carolinensis)*		X	X									
Great Blue Heron *(Ardea Herodias)*							X					
Great-Crested Flycatcher *(Mylarchus Crinitus)*					X							
Great Egret *(Casmerodius Albus)*							X					
Great Horned Owl *(Bubo Virginianus)*				X								
Greater Yellowlegs *(Totanus Melanoleucus)*							X					
Green-Winged Teal *(Anas Carolinensis)*							X					
Grosbeak *(Hesperiphona Vespertina)*												X
Herring Gull *(Larus Argentatus)*							X					
Horned Grebe *(Podiceps Auritus)*							X					
Killdeer *(Charadrius Vociferous)*									X			
Long-Billed Marsh Wren *(Termatodytes Palustris)*							X					
Marsh Hawk *(Circus Cyaneus)*							X					
Mourning Dove *(Zenaida Macroura)*									X			
Nuthatches *(Family Sittidae)*				X								
Nuthatch *(Sitta Carolinensis)*												X
Osprey *(Pandion Halleetus)*							X	X		X		
Ovenbird *(Selurus Aurocapillus)*					X							
Pigeon *(Columbia Livia)*	X											
Pine Warbler *(Dendroila Pinus)*					X							
Red-Eyed Towhee *(Pipilo Erythrophthalmus)*		X										

Table 12 cont.

NATURAL HABITATS AND SPECIES

SPECIES	HABITAT											
Common *(Scientific)*	Urban Area	Hardwood Young	Hardwood Medium	Hardwood Mature	Mixed Forest Med.	Mixed Forest Mat.	Marsh	Abandoned Field	Tilled Filled	Maintained Field	Mowed Field	Non-Urban Landscaped
BIRDS												
Red-Eyed Vireo *(Vireo Olivaleus)*					X							
Red-Shouldered Hawk *(Buteo Lineatus)*					X			X		X		
Red-Tailed Hawk *(Buteo Jamaicensis)*				X				X		X		
Red-Winged Blackbird *(Agelaries Phoeniceus)*									X		X	
Red-Necked Pheasant *(Phasianus Colchicus)*									X			
Robin *(Turdus Migratorius)*												X
Titmice *(Family Paridae)*				X								
Turkey Vulture *(Cathartes Aura)*					X							
Warblers *(Family Compsothlypidae)*		X	X							X		
Whip-Poor-Will *(Caprimulgus Vociferus)*					X							
Willet *(Catoptrophorus Semipalmatus)*							X					
Woodpeckers *(Family Picidae)*				X								
Woodthrush *(Hylocichla Musterina)*		X	X									
Wrens *(Family Troglodytidae)*										X		
Ruby-Crowned Ringlet *(Regulus Calendula)*					X							
Ruby-Throated Hummingbird *(Archilodus Colubris)*		X	X									
Ruby Turnstone *(Arenaria Interpres)*							X					
Screech Owl *(Otus Asio)*								X	X			
Seaside Sparrow *(Ammospiza Maritima)*							X					
Semipalmated Sandpiper *(Ereunetes Mauri)*							X					
Snowy Egret *(Leucophoya Thula)*							X					
Starling *(Sturnus Vulgaris)*	X											
Swallows *(Family Hirundinidae)*										X		
MAMMALS												
Brown Bat *(Eptesicus Floridanus A Fuscus)*					X							
Domestic Cat *(Felis Domesticus)*	X										X	
Domestic Dog *(Canis familiaris)*	X										X	
Eastern Chipmunk *(Tamias Striatus)*					X							

TABLE 12

NATURAL HABITATS AND SPECIES

SPECIES	HABITAT											
	Urban Area	Hardwood Young	Hardwood Medium	Hardwood Mature	Mixed Forest Med.	Mixed Forest Mat.	Marsh	Abandoned Field	Tilled Filled	Maintained Field	Mowed Field	Non-Urban Landscaped
Common **(Scientific)**												
MAMMALS												
Eastern Cottontail *(Sylvilagus Floridanus)*		X			X		X	X				X
Eastern Gray Squirrel *(Sciurus Carolinensis)*			X	X	X							
Eastern Grey Squirrel *(Sciurus Carolinensis)*												
Eastern Mole *(Scalopus Aquaticus)*					X						X	
House Mouse *(Mus Musculus)*	X							X			X	
Masked Shrew *(Sorex Cinereus)*				X			X		X			
Meadow Vole *(Microtus Pennsylvanicus)*		X					X	X	X		X	X
Muskrat *(Ondatra Zibethicus)*							X					
New England Cottontail *(Sylvilagus Transitionalis)*					X			X				X
Norway Rat *(Rattus Norvegicus)*	X											
Opossum *(Didelphis Marsupialis)*				X	X		X		X	X		
Pine Vole *(Pitymys Pinetorum)*					X							
Raccoon *(Procyon Lotor)*					X		X	X	X			
Red Bat *(Lasiurus Borealis)*				X								
Red Fox *(Vulpes Fulva)*			X	X	X		X			X		
Red Squirrel *(Tamiasciurus Hudsonicus)*					X							
Rice Rat *(Oryzomys Palustris)*							X					
Shorttail Shrew *(Blarina Brevicanda)*					X							
Striped Skunk *(Mephitis Mephitis)*		X			X		X		X	X		
Weasel *(Mustela Sp)*							X					
White-Footed Mouse *(Peromyseus Leucopus)*		X			X							
White-Tailed Deer *(Odocolleus Virginianus)*			X	X	X		X					

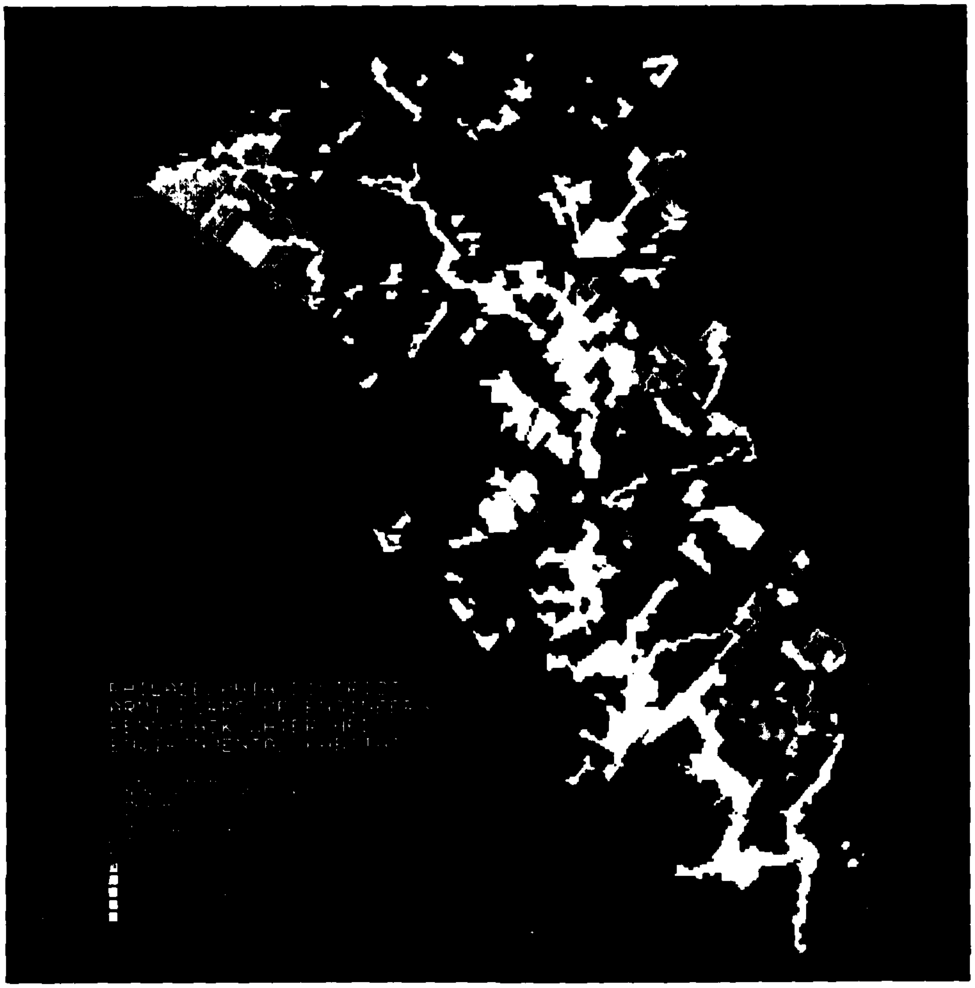

PLATE 10
ENVIRONMENTAL HABITAT

TABLE 13				
NATURAL HABITATS AND SPECIES				
	EXISTING LAND USE	ALTERNATIVE C LAND USE PLAN	LOSS OF HABITAT AREAS	
ENVIRONMENTAL HABITAT TYPE[1]	ACRES	ACRES	DIFFERENCE IN ACRES	%-CHANGE
Young Hardwood Forests	302	7	295	97.7
Medium Hardwood Forests	907	264	643	70.9
Mature Hardwood Forests	3821	1738	2083	54.5
Medium Mixed Forest	0	0	0	0
Mature Mixed Forest	7	0	7	100.0
Marsh	32	3	29	90.6
Abandoned Fields	623	26	597	95.8
Tilled Fields	988	33	955	96.7
Maintained Fields	1111	221	890	80.1
Mowed Fields	1781	990	791	44.1
Non-Urban Landscaped Areas	187	20	167	89.3
TOTALS[1]	9759	3302	6457	66.2

[1]Based on Rural Land Use Only. Total number acres in watershed: 35,645

WATER QUALITY EVALUATION

A preliminary analysis of the impact of changing land use on the general water quality of the watershed was made by accessing pertinent data in the grid cell data bank and performing assessments through computerized techniques. It was recognized at the outset that other techniques were available for water quality assessment. However, these techniques were not readily suited or adaptable to a grid cell data bank system. Because the overall goals of the study were the development and maximum use of a comprehensive data bank with automated techniques, this pilot study was extended to include water quality impacts.

Under existing conditions, water quality in the watershed is fairly typical of a predominantly urbanized watershed. With 64% urbanization, there are numerous sources of point and non-point pollution affecting water quality.

A direct impact of increasing urbanization is the generation of additional domestic, commercial and industrial waste. The treatment of this waste, whether by individual systems or large sewage treatment plants, results in the release of various outflows carried by effluent waters into surface and ground water systems. These products of treatment are predominantly nutrients, organic matter and bacteria.

An additional impact of increasing urbanization can be an increase in storm water runoff. This is primarily due to an increase of impervious surfaces that prevent percolation of rainfall into the ground and subsequent diversion of this water into surface waters via storm water collection systems. Storm water runoff can include suspended solids; organic matter available for organisms such as fish; nutrients such as nitrogen and phosphorous resulting from fertilizer application; detergents used in auto washing; coliform bacteria; heavy metals and pesticides. Significant quantities of these substances in surface and ground water can have an adverse effect on water quality.

In order to provide general, relative information on water quality in the watershed, a comparison was made of Existing Land Use with Alternative B Land Use. The geographic data bank, interfaced with available water quality data, was used as the basis for land use input to the storm runoff computer model Storage, Treatment, Overflow Runoff Model (STORM).[10] This is a continuous simulation computer model designed for use in metropolitan master planning studies to evaluate storage and treatment capacities required to reduce raw sewage overflows. The STORM runoff module determined the quantity and quality of land surface runoff. A receiving (in-stream) water quality module[17] was developed specifically for this study to simulate water quality in the stream network. Thus, the land surface runoff generated by the runoff module was input to the receiving water model to simulate the resultant stream water quality.

The general procedure used in the calibration of STORM for quantity of runoff was to make initial adjustments based primarily on volumes, and subsequent adjustments based primarily on hydrograph shapes. Once the quantity calibration was satisfactory, the quality adjustments were made. Due to limited sample data, the time-quality relationship could not be conclusively defined, and no attempt was made to reproduce the time value of concentration for the measured events. Instead, the model parameters were adjusted to reproduce the mean value of the concentrations for each of the measured events. Water quality data do exist as baseflow concentrations above the Upper Moreland-Hatboro Sewage Treatment Plant (UMH) and as effluent concentration sampled from the plant. Calibration of several model coefficients was performed using these available input values.

Several water quality parameters were selected to simulate the effects of development on storm water runoff and dry flow conditions. They are: water temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia nitrogen, orthophosphate phosphorus (PO_4) and fecal coliforms.

TABLE 14

COMPARISON OF LOADING COMPONENTS

	% of Total Load			
Existing Land Use	**CBOD**	**NBOD**	**PO_4**	**Fecal Coliform**
Surface Runoff Quality	74.5	4.5	28.0	99.7
Sewage Treated Effluent	24.5	93.5	67.5	0.1
Base Flow Quality	1.0	2.0	4.5	0.2
Alternative B				
Surface Runoff Quality	53.5	2.0	14.0	99.7
Sewage Treated Effluent	46.0	97.5	84.0	0.1
Base Flow Quality	0.5	0.5	2.0	0.2

The impact of changing land use on these parameters was evaluated by comparison of the Existing Land Use and Alternative Plan B Land Use Plan. As one might expect, the water quality of the Pennypack Watershed generally worsened as a result of increasing development. Table 14 shows a comparison of the loading components as a percentage of total load. It can be seen that surface runoff contributes the majority of the carbonaceous biochemical oxygen demand (BOD) and fecal coliform loadings, while the treated sewage effluent is responsible for the majority of the nitrogeneous biochemical oxygen demand (NBOD) and PO_4. A comparison of existing and estimated future conditions is shown on water quality profiles Plates 11 through 16. These profiles show the maximum and/or minimum simulated conditions for each water quality parameter. They also show the values that occurred 50% of the time during the study period for existing land use and simulated 50% values for the Alternative B land use. On all plates the proposed Pennsylvania State In-stream Water Quality Standards have also been shown for comparison. The maximum simulated values were compared to maximum pollutant concentration measured in other parts of the country and found to be within an average range of observed values. A summary of expected water quality impacts is given in Table 15.

Care should be exercised not to misinterpret the *relative* water quality impacts generated by these preliminary analyses, or utilize them for decision-making where more site-specific and refined water quality information is necessary. While the general goals of this phase of the study were met in the development of an automated in-stream water quality model, the results presented in this report should be regarded only as general indications of trends in water quality that may be expected as development continues to increase in the watershed.

Perhaps the most significant result of this phase of the study has been the development of a framework for future water quality analyses utilizing automated, systematic techniques from a computerized data bank system. As more water quality data become available, these techniques can be further refined and calibrated to produce even more meaningful information for comprehensive planning.

TABLE 15

WATER QUALITY COMPARISON OF EXISTING AND ESTIMATED FUTURE CONDITIONS (ALTERNATIVE B)

Parameter	Impact of Future Conditions	Parameter	Impact of Future Conditions
Temperature	Not significant. (See Plate 11.)	Ammonia Nitrogen	In general, about 0.5 mg/l increase in the headwater channel and 1 to 2 mg/l increase throughout remainder of channel. Largest impact is immediately downstream of UMH discharge. This increase has no significant impact on already low DO level. If existing conditions were improved, this NH_3 increase would be very significant, since the increase itself equals NH_3 standard. (See Plate 14.)
Dissolved Oxygen	Up to 1 mg/l decrease in DO in the headwater channel above the UMH discharge. No other significant impact between future and existing conditions. While 1 mg/l would usually be considered significant change, and since the remainder of the profile (See Plate 12) is so far below standards, the upstream impact is generally inconsequential.		
Biochemical Oxygen Demand	In general, about 3 to 4 mg/l increase in BOD concentrations. This increase has no significant impact on the already low DO level. If existing conditions were improved, this BOD increase might be very significant. (See Plate 13.)	Orthophosphate Phosphorus	In general, about 1 mg/l increase in headwater channel and 1.5 to 2 mg/l increase throughout remainder of channel. This is a significant increase which far exceeds the standard. (See Plate 15.)
		Fecal Coliform	In general 10 to 15% increase throughout study area. This increase is insignificant compared to magnitude of existing condition. (See Plate 16.)

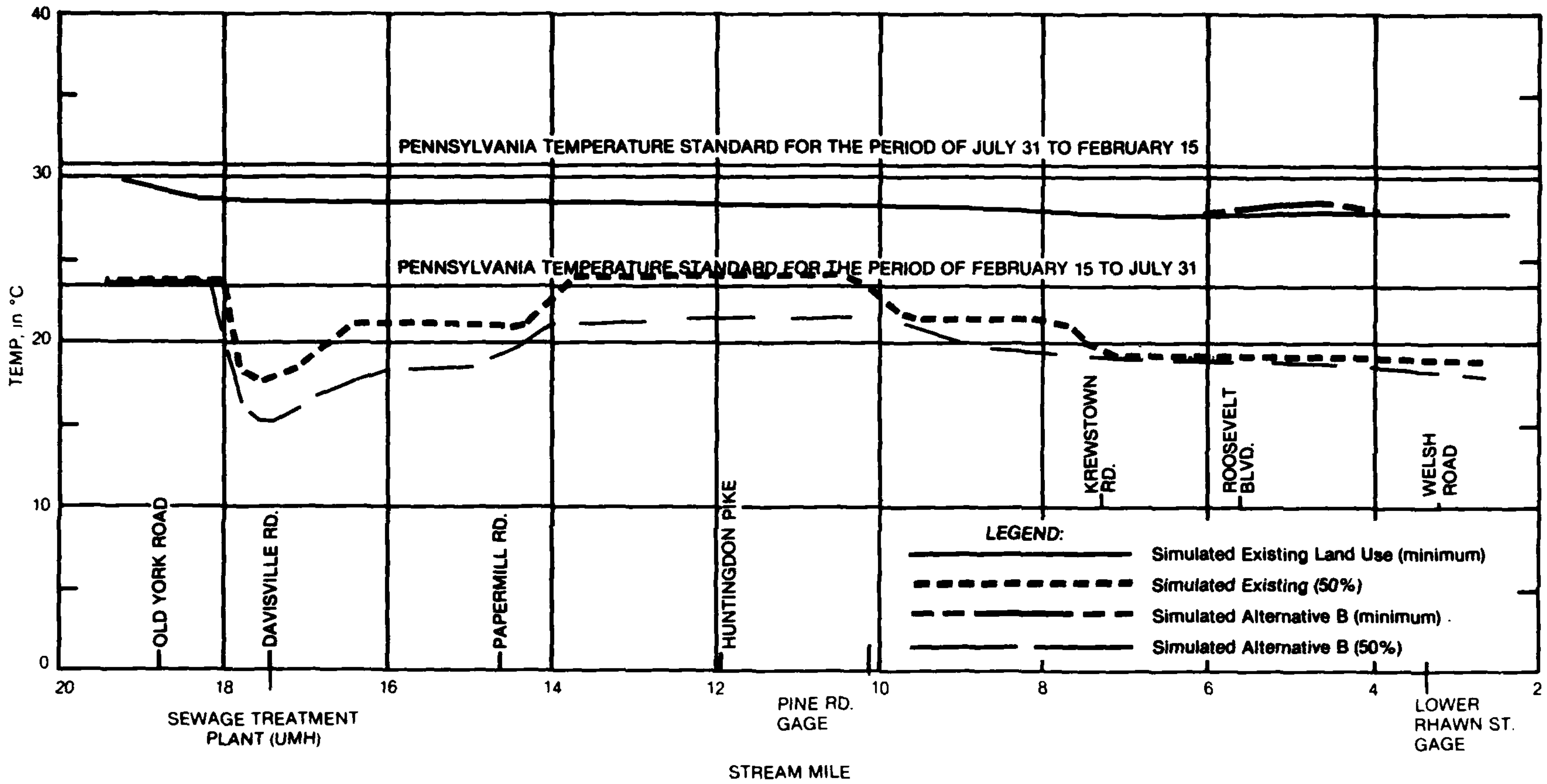

PLATE 11

PENNYPACK WATERSHED

WATER TEMPERATURE PROFILES FOR EXISTING AND ALTERNATIVE B LAND USES

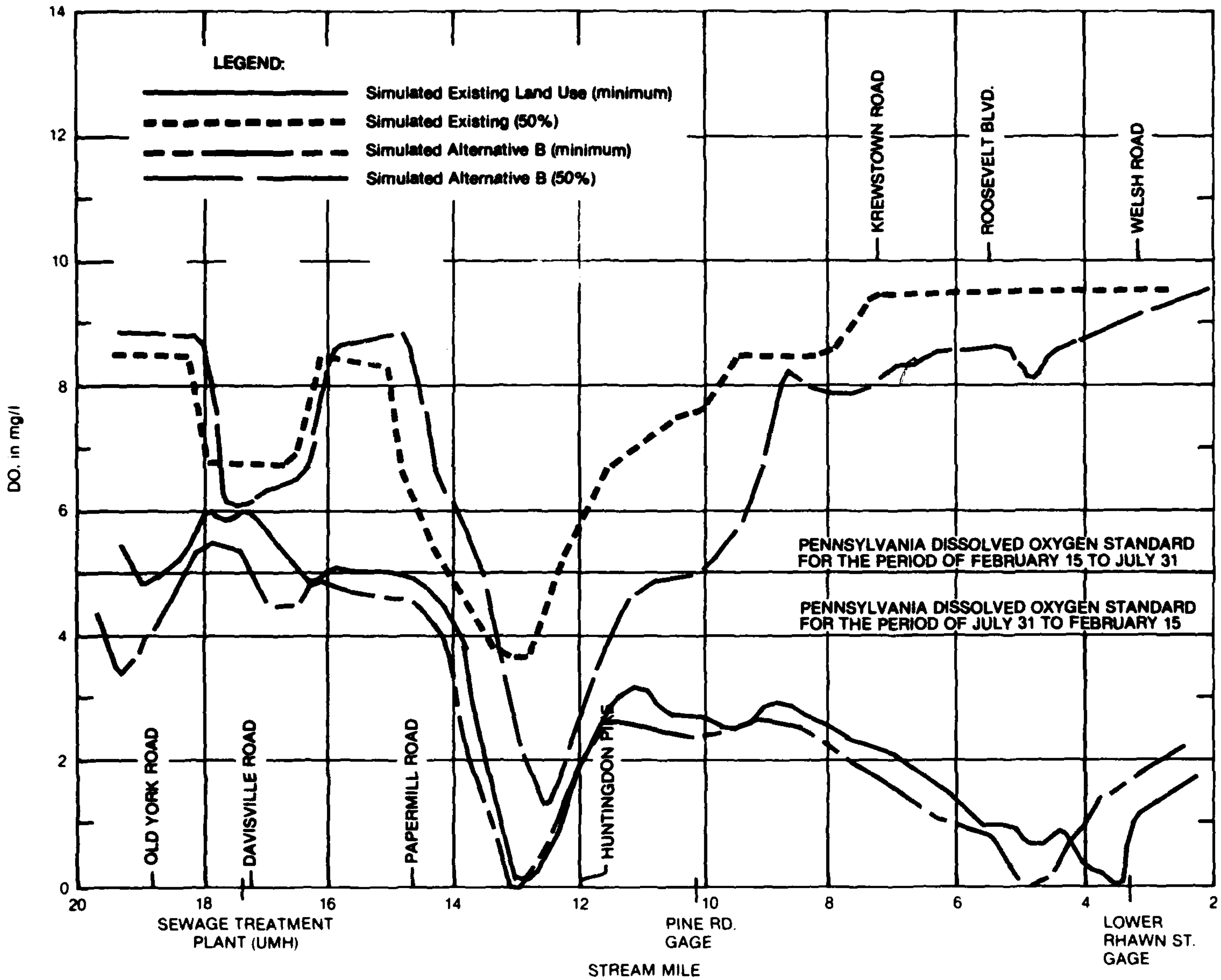

PLATE 12

PENNYPACK WATERSHED

DISSOLVED OXYGEN PROFILES FOR EXISTING AND ALTERNATIVE LAND USES

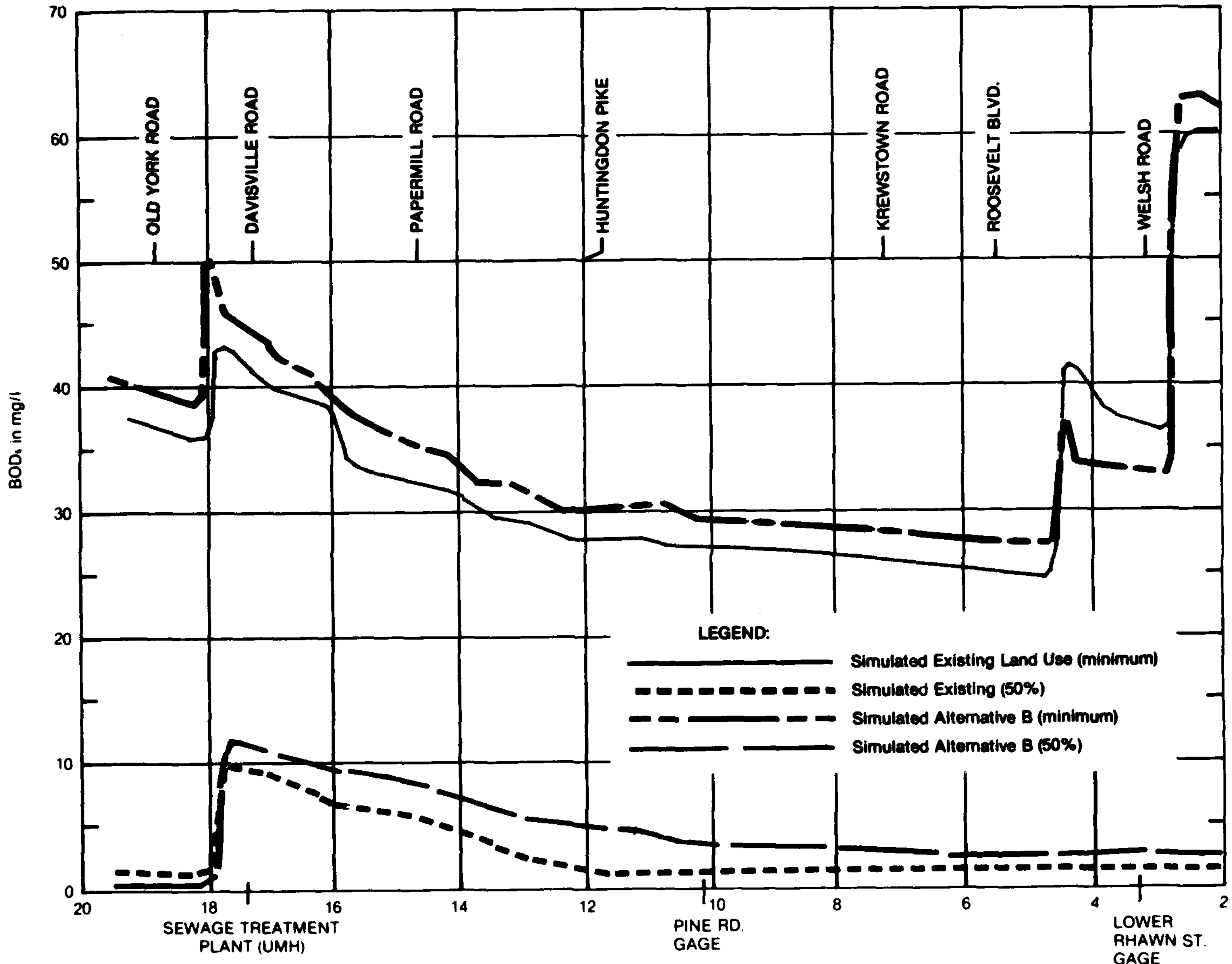

PLATE 13

PENNYPACK WATERSHED

CARBONACEOUS BIOCHEMICAL OXYGEN DEMAND PROFILES FOR EXISTING AND ALTERNATIVE B LAND USES

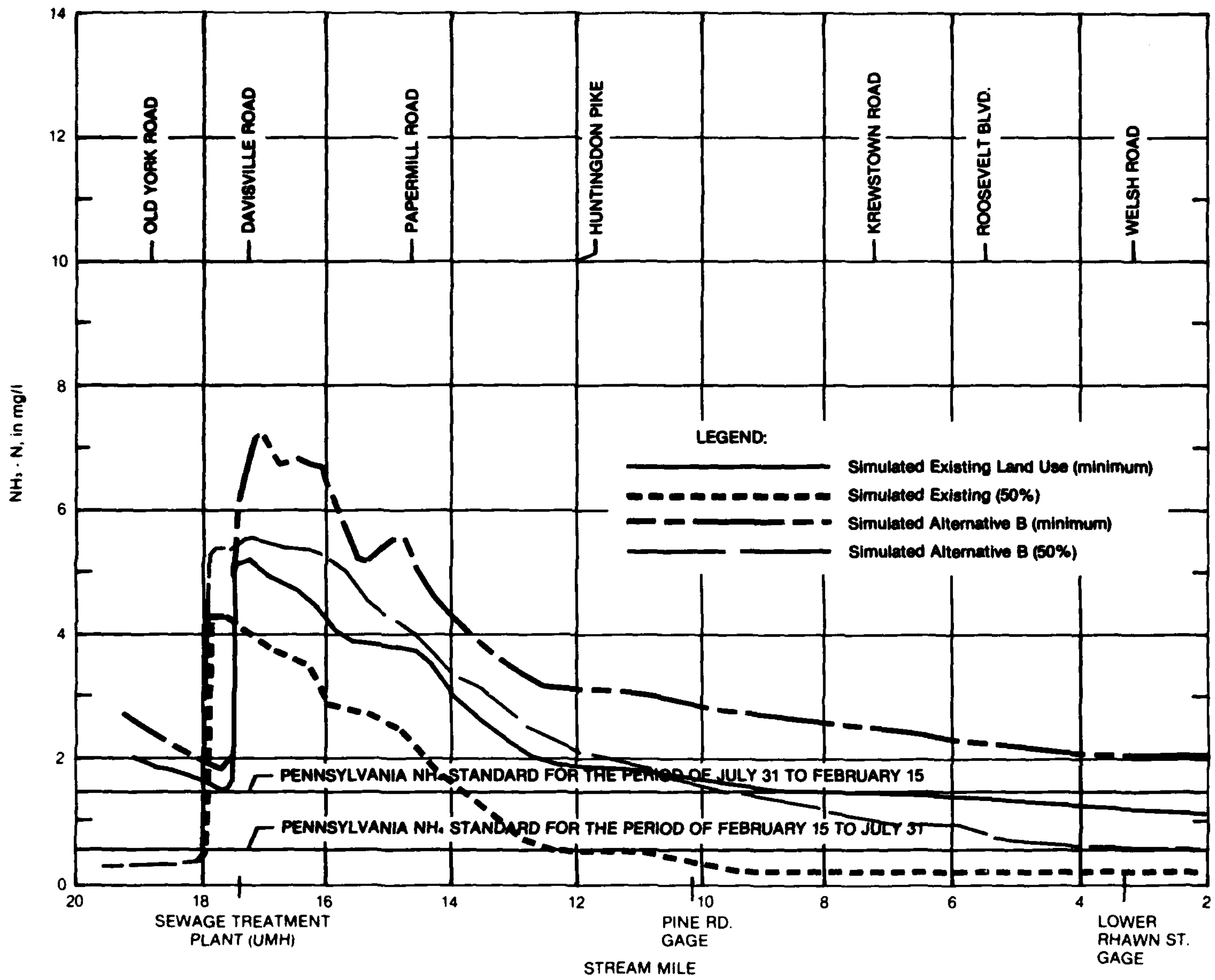

PLATE 14

PENNYPACK WATERSHED

AMMONIA NITROGEN PROFILES FOR EXISTING AND ALTERNATIVE B LAND USES

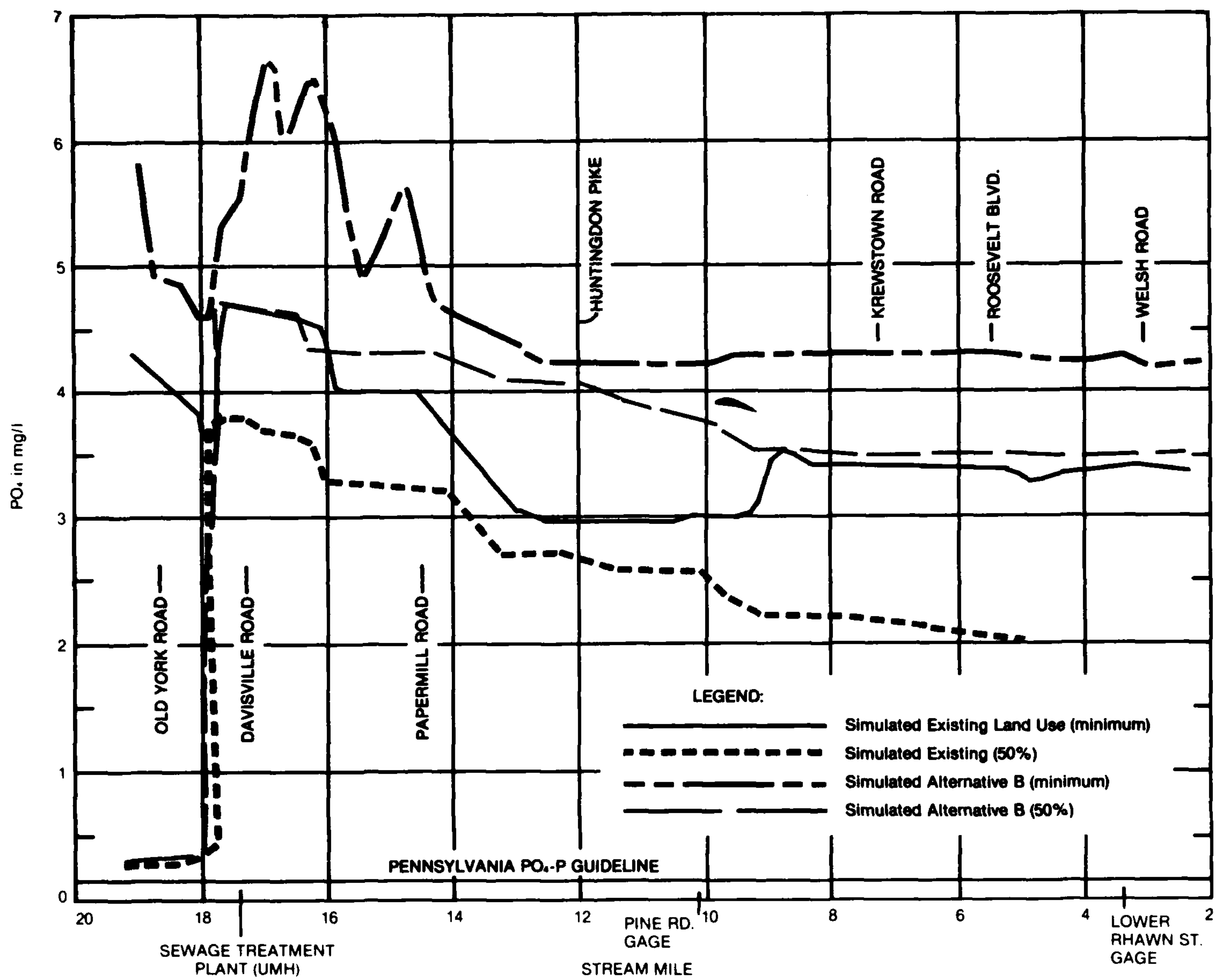

PLATE 15

PENNYPACK WATERSHED

ORTHOPHOSPHATE PHOSPHORUS PROFILES FOR EXISTING AND ALTERNATIVE B LAND USES

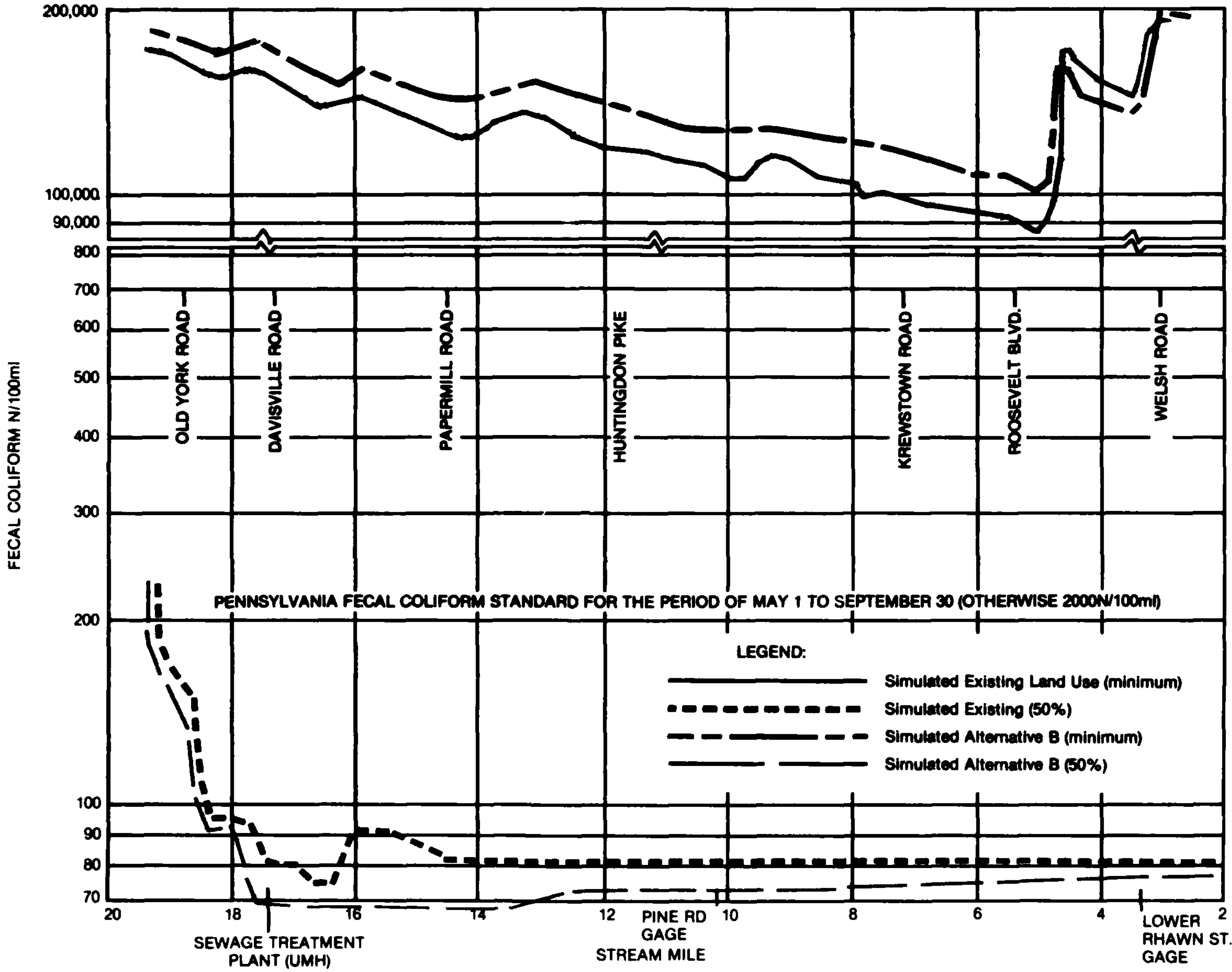

PLATE 16
PENNYPACK WATERSHED
FECAL COLIFORM PROFILES FOR EXISTING AND ALTERNATIVE B LAND USES

OTHER DATA BANK USES AND PRODUCTS

Resource Information and Analysis

For broad-based, comprehensive planning purposes, many types of resource information need to be considered in order to balance the developmental, environmental and community service needs of the region. Manual techniques of resource data management are often cumbersome and inefficient. As a result, important resource features may go undiscovered during the planning process. However, computerized techniques are emerging that can significantly broaden the planner's capability to analyze large quantities of diverse data and answer a variety of pertinent questions during the planning process.

For this study, the environmental analysis capabilities for the watershed were broadened by incorporating a system of Resource Information and Analysis (RIA) programs[9] developed by the Hydrologic Engineering Center. This system is based on a series of computer programs developed by the Harvard Laboratory for Computer Graphics and Spatial Analysis. The Hydrologic Engineering Center made extensive modifications to these programs to meet the needs of comprehensive, basin-wide studies utilizing digital data bank technology. Any number of resource information questions can be asked of the data bank, provided that the pertinent resource information characteristics can be mapped and subsequently represented in digital form.

The RIA programs in this study catalogued certain physiographic and environmental features of the watershed and provided the capability to access the data bank and identify and analyze resource information by four basic techniques:

- Distance Determination
- Locational Attractiveness
- Impact Analysis
- Coincident Tabulation

All the above capabilities of RIA can be combined creatively to search, compare and identify resource information in the data bank. In this way, decision-makers can have available watershed data at their disposal in a form most suitable for making informed land use and floodplain management decisions.

Distance Determination

This option of RIA calculates the linear distance to/from grid cells with certain characteristics of interest. For example, a distance determination could be performed to calculate the linear distance of each grid cell in the data bank from all adjacent cells categorized as agricultural land use. The result can be displayed as a computer-printed map of coded symbols representing calculated distances for a specific data category (agriculture) within a single data variable (land use). Calculations may also be performed among multiple data categories within several data variables. Plate 17 depicts the computer-mapped output of a distance determination to calculate the distance of each grid cell in the data bank from all cells classified as industrial land use under existing conditions. The shading of the symbols on the map varies from light to dark as the distance from grid cells of industrial land use increases. Prominent corridors of industrial activity are clearly visible as the lightly shaded areas on the map. This information is provided as a sample of distance determination data that can be useful to the planner in siting certain land uses, either near to or far from industrial areas. The same basic technique can be used to determine distance relationships among any variables in the data bank.

Locational Attractiveness

This option of the RIA program package allows calculation of relative attractiveness values or "scores" for a particular set of value judgments. The spatial or locational characteristics of an area (either single or multiple grid cells) are scored for their relative attractiveness under subjective criteria assigned by the analyst. For example, if one wished to locate those areas most attractive for potential stream valley park locations, one could assign weighting values to the data (in priority order) for those criteria considered to be desirable for such park locations. The locational attractiveness program could then automatically add the scores for each individual grid cell, and generate mapped output indicating those cells with the highest relative score as those most attractive for park locations.

Plate 18 is an example of locational attractiveness simulation for potential stream valley park locations in the Pennypack Watershed, which was determined by considering:

- Existing land use: natural vegetation, residential and pasture lands, etc. are favored over other categories;
- Linear features: areas near streams are favored over other sites;
- Environmental habitat: areas with mature trees and water bodies are favored over other sites;
- Topography/slope: flat and mild slopes are favored over steeper terrain;
- Distance to industry: areas farther are favored over sites closer to industrial areas; these data were obtained from a distance determination assessment as described previously.

All data variables were assigned equal weighting except existing land use, which was considered to be twice as important as the other characteristics involved. The computer map for this locational attractiveness model shows many areas along Pennypack Creek and its tributaries that would be potentially suitable sites for stream valley parks

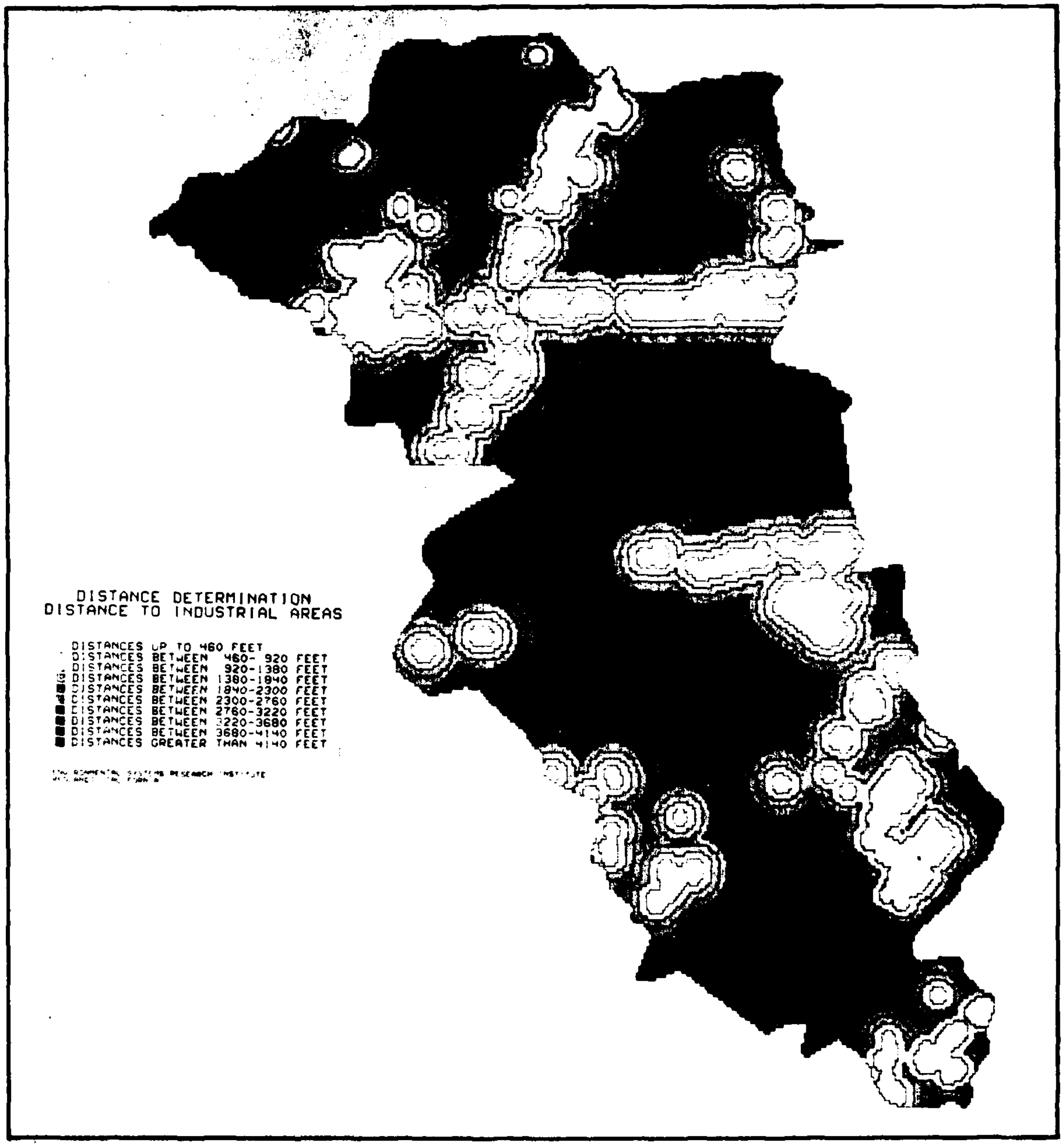

PLATE 17
DISTANCE DETERMINATION —
INDUSTRIAL ACTIVITY

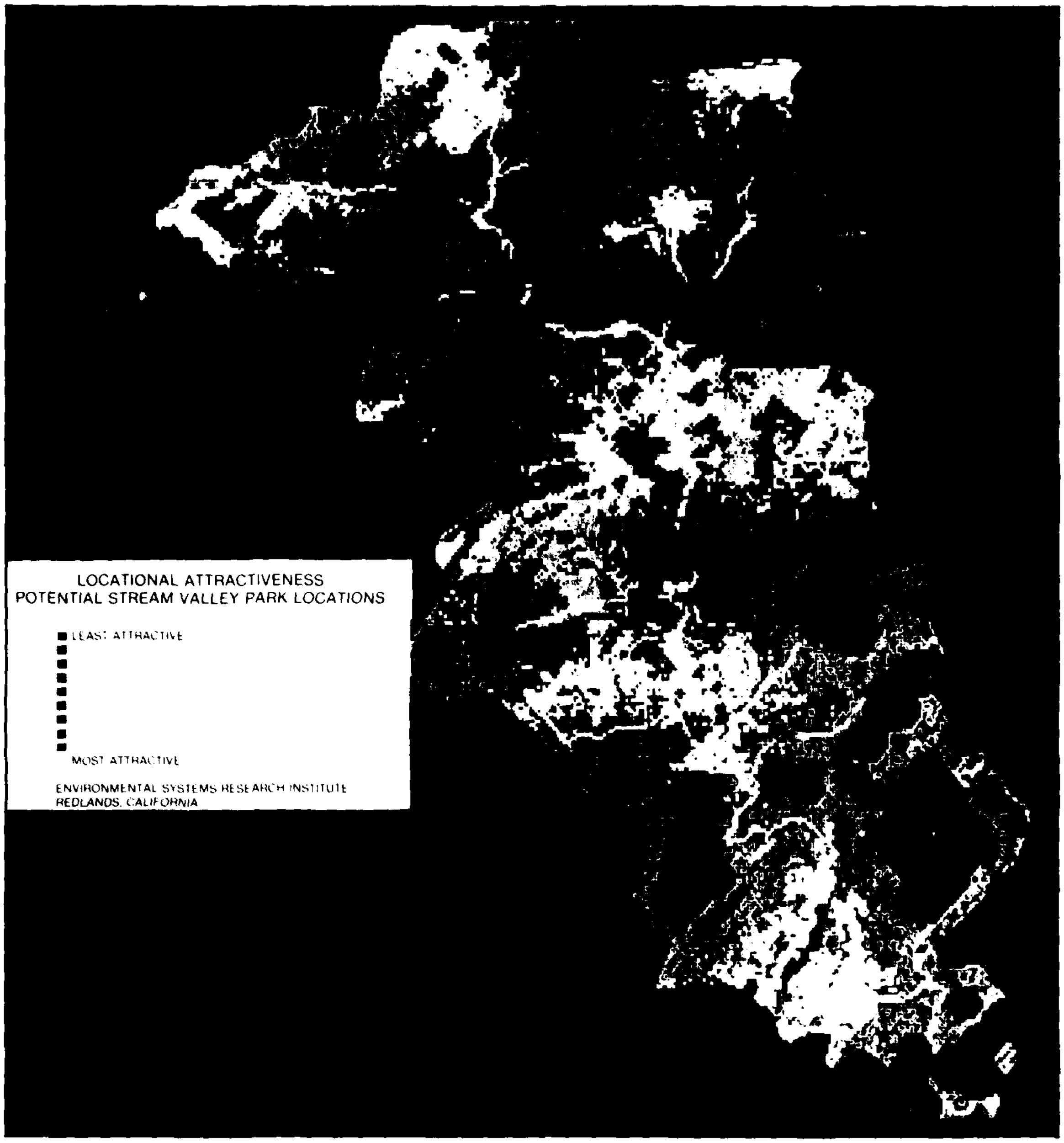

PLATE 18
LOCATIONAL ATTRACTIVENESS —
STREAM VALLEY PARKS

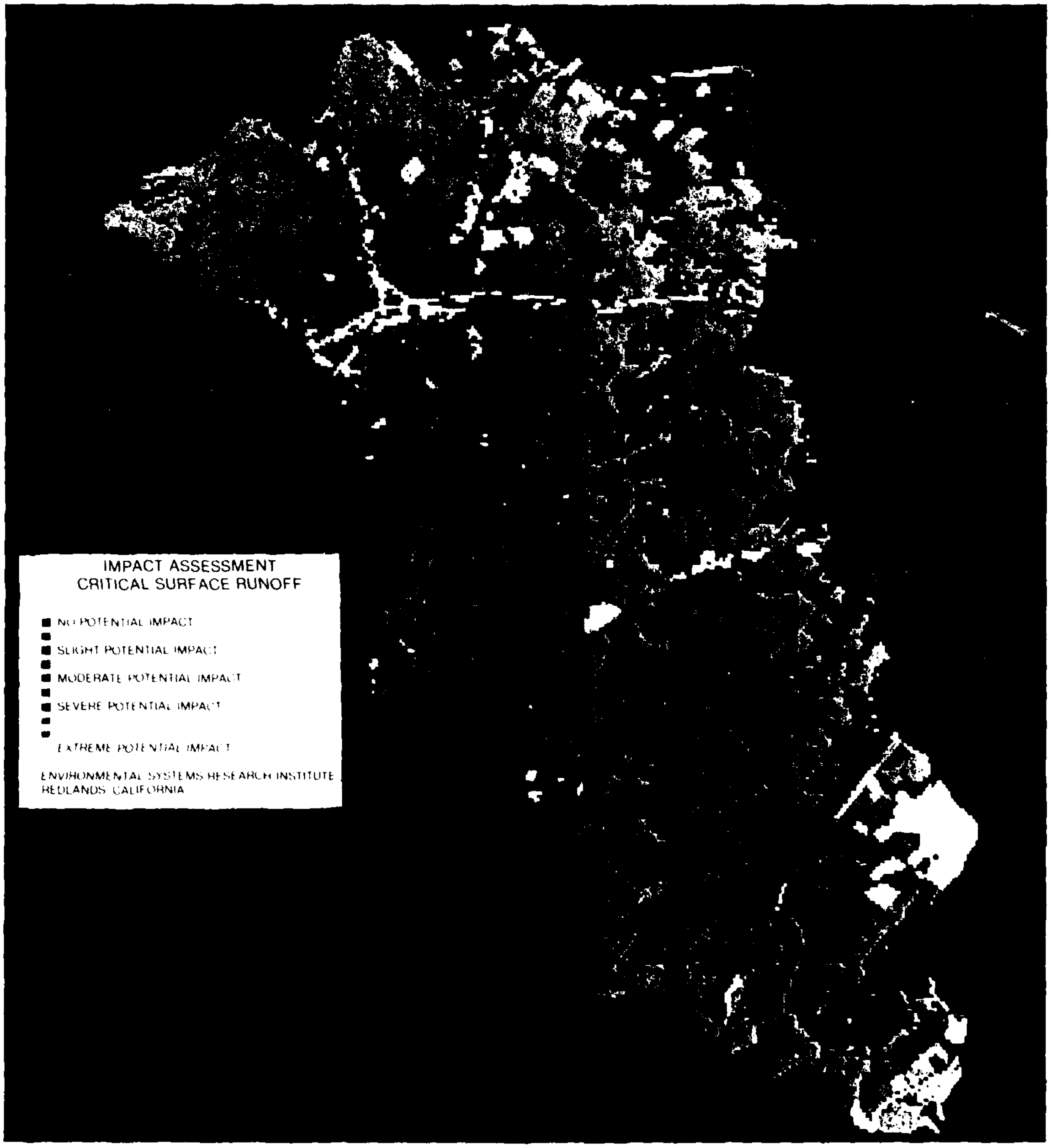

PLATE 19
IMPACT ANALYSIS —
CRITICAL SURFACE RUNOFF

based on the above criteria. On the map, the solid, dark shading represents areas most "attractive" for stream valley park locations. Less attractive sites are shown by progressively lighter shading. This type of "attractiveness" analysis and mapping could be performed for a variety of planning purposes.

Impact Analysis

This option of the RIA package permits relative impact assessment of interactions among several resource data variables. Relative impacts are categorized from slight to severe based on weighted numerical scores of sensitivity to the particular set of criteria under consideration. In combination with the locational attractiveness (and mapping) options, computer maps can be produced to display those areas of minimum to maximum impact for a given activity of interest.

Plate 19 shows potentially critical areas of surface runoff in the watershed developed by considering existing land use and hydrologic soil types for their combined impact on runoff potential. For example, high density development located in areas of low soil permeability would combine to have a high potential for surface runoff. Conversely, low density or undeveloped areas with high soil permeability would have significantly less potential for producing large quantities of surface runoff. On the map the dark, solid shading indicates areas of relatively higher potential for surface runoff.

Coincident Tabulation

This feature of RIA is available for inventory-type identification of the coincident occurrence of two or more data variables, generally within a geographic or locational boundary such as sub-basin, damage reach or community. This resource management tool can be used to monitor physical changes in the watershed such as increasing or decreasing acreages of particular land use categories from existing to future conditions. Table 13, Natural Habitat Areas, was generated by the coincident tabulation feature of the RIA system. This resource information tool can also be valuable for searching the data base for the coincidence of attributes that may be important for more informed land use planning.

Watershed Mapping

Base mapping of the Pennypack Watershed was required for accurate delineation of all spatial, linear, contour and point data, and precise definition of grid cells. Because existing mapping of the watershed from known sources did not fully meet the technical requirements of the study, new base mapping was prepared for the entire area.

Orthophotography was chosen as the base for this new watershed mapping because of two major advantages over other map formats:

- It displays all physical characteristics of the ground surface discernable from aerial photographs — including land use, ground cover, transportation routes and water courses.
- It is precisely controlled by field surveys and mathematically corrected to remove all displacements, rotations and distortions in both horizontal and vertical planes; orthophotography is a directly scalable map that allows precise measurement of distances, dimensions and areas, and meets national map accuracy standards (within 1/40″ at map scale).

The watershed mapping developed for use in the study consists of a 1:4800 (1″ = 400′) orthophoto base map with the following data overlays:

- 4′ contour interval topographic data from conventional photogrammetric techniques;
- State Plane Coordinate Grid System
- Universal Transverse Mercator (UTM) Coordinate Grid System
- Grid System and numerical row/column identifications for 80′ × 100′ (0.20 acre) and 160′ × 200′ (0.75 acre) grid cell boundaries defined for digital data bank construction.

This orthophoto base mapping is a valuable by-product of the study that can be useful for a variety of future planning and engineering purposes. Twenty-five map sheets covering the Pennypack Watershed area are available for inspection at the offices of the U.S. Army Corps of Engineers, Philadelphia District, or from the Pennypack Watershed Association. (See Plate 20.)

Additional Technical Services

Updating: This may be necessary as significant physical and/or policy changes affect areas of the watershed and their interrelationships. Updating the data bank and performing new computer analyses are done on a case-by-case basis; requests for these services should be made to the appropriate County Planning Commission or the Pennypack Watershed Association.

Further Analyses: The scenarios of possible future land use and alternative policies analyzed and presented in this study were chosen as the most meaningful for future planning purposes, based on current trends in the watershed. However, the possibility of other alternative land use plans and policies emerging over time was recognized at the outset of this study, and planned for by the creation of the computerized grid cell data bank. The data bank remains available for future analyses, of the type presented in this study, for other land use management plans that local agencies and governments might wish to consider.

In addition, the grid cell data bank represents a wealth of watershed data that can be accessed, reviewed and mapped for a variety of planning purposes. Special computer programs are available that can search the data bank for the coincidence of desired watershed characteristics, calculate attractiveness "scores," and provide distance determinations to or from physical attributes of the watershed that may be important for general land use planning.

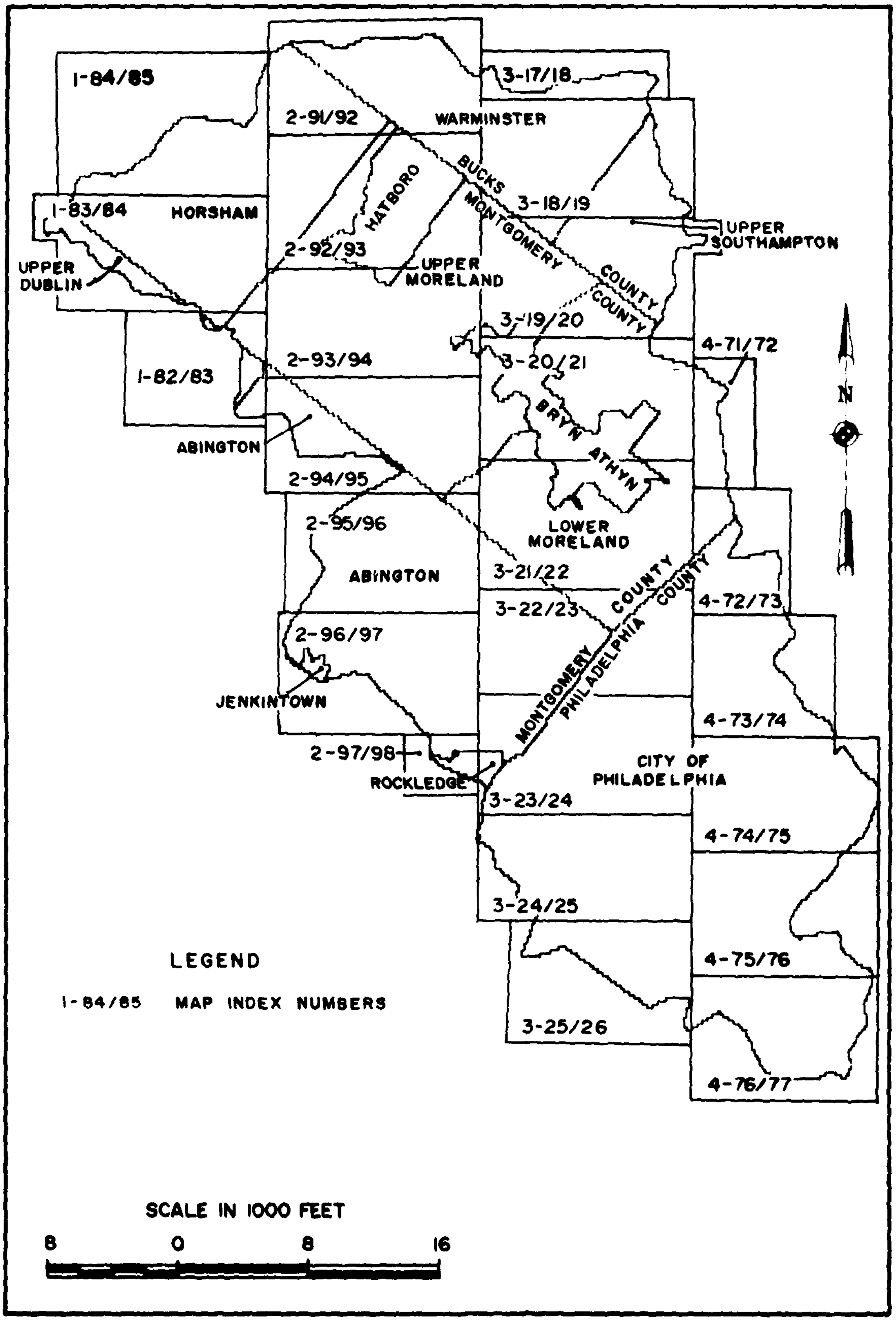

PLATE 20
ORTHOPHOTO INDEX

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GLOSSARY OF TERMS

Alternative Future Land Use Plan: A land use configuration which could occur in the future and which is consistent with population projections and land use regulations. In this study, the future land use plans were developed by the Philadelphia County Planning Commission, the City of Philadelphia, the Bucks County Townships of Upper Southampton and Warminster, and the Pennypack Watershed Association.

Assessment: A quantitative and/or qualitative evaluation. This study evaluated the impact on hydrologic, hydraulic, economic, and environmental conditions that would result if any one of a selected number of alternative futures were to occur.

Average Annual Damage: The weighted average of damage potential for a full range of damaging flood events. It can be viewed as the average damage potential that might be expected to occur in any present or future year.

Basin: See Watershed.

Biochemical Oxygen Demand (BOD): Measures the effect of organic matter and the amount of dissolved oxygen (D.O.) in water. A low dissolved oxygen concentration in surface waters may contribute to an unfavorable environment for fish and other aquatic species, and the absence of dissolved oxygen may give rise to odoriferous products of anaerobic (absence of oxygen) decomposition.

Computer Data Bank: Computer files of spatial (mapped) data which are registered to a common base and stored in a computer file system, and which can be rapidly recalled for a multitude of uses. The data for this study were stored in a 0.20 and 0.75 acre grid cell format.

Contour Interval: A contour is the outline of a land surface which has the same elevation. On a topographic map contour lines are shown at regular intervals of elevation. The topographic maps used in this study show one contour line for every four-foot change in elevation.

Damage Reach: A segment of a floodplain along a stream in which relatively uniform flood hazard conditions prevail and, hence, is a workable unit for hydrologic and economic (flood damage) computations.

Digitizing: An automated technique for data encoding which uses specialized equipment to define and record data boundaries in the memory of the computer.

Discharge: As applied to a stream, the rate of flow for a given rainfall-runoff condition at a given location, usually measured in cubic feet per second (cfs). Also see Discharge-Frequency.

Discharge-Frequency: A means of expressing the (exceedance) probability of flood occurrences as determined from a statistical analysis of streamflow or rainfall and runoff records. A 10-year frequency flood would have an average frequency of occurrence on the order of once in 10 years (a 10 percent chance of being equalled or exceeded in any given year). A 500-year frequency flood would have an average frequency of occurrence on the order of once in 500 years (a 0.2 percent chance of being equalled or exceeded in any given year).

Drainage Area: An area of land which contributes to the flow of water in a stream or river.

Encoding: Assigning data values to a fixed grid cell network, in order to construct a data bank.

Existing Land Use: Baseline land use conditions in the watershed compiled from available mapping and tax records, and updated using 1977 aerial photography.

Fecal Coliform: The presence of coliform bacteria including those that are of intestinal organisms (fecal coliforms) in a water body indicates the possible presence of pathogenic (disease causing) organisms. Coliform bacteria enter surface bodies from domestic sewage treatment effluent as a result of coliforms that are part of human excretion and in storm water runoff as a result of domestic and wild mammals, birds and amphibians. The presence of high coliform concentrations in surface waters indicates a potential danger of contracting gastrointestinal illnesses and eye, ear, nose and throat irritation by swimmers and bathers.

Flood: An overflow of water on land not normally covered by water. Floods have two essential characteristics; the inundation of land is temporary; and the land is adjacent to and inundated by overflow from a river, stream or ocean, lake or other body of standing water. Normally, a "flood" is considered as any temporary rise in streamflow or stage, other than the ponding of surface water, that results in significant adverse effects in the vicinity. Adverse effects may include damages from overflow of land area, temporary backwater effects in sewers and local drainage channels, creation of unsanitary conditions or other unfavorable situations by deposition of materials in stream channels during flood recessions, rise of ground water coincident with increased streamflow and other problems. Also see Discharge.

Floodplain: The relatively flat area or lowlands adjoining the channel of a river, stream or watercourse or ocean, lake or other body of standing water, which have been or may be covered by floodwater.

Floodplain Management: Any action which is directed toward the wise use of floodplains. This action generally involves the reduction and/or prevention of flood damage and protection of environmental values, while at the same time leading to the prudent use of the floodplain.

Floodproofing: Changes or adjustments to properties and/or structures that reduce or eliminate flood related damages. Although many forms of floodproofing are available only closure of openings was evaluated for this study.

Floodway Fringe: That portion of a floodplain which is between the floodway and the boundary of the 100-year flood.

Habitat: A natural abode (place) of a plant or animal where it normally grows or lives.

Hydraulics: The branch of physics having to do with the mechanical properties of water and with the application of these properties in engineering.

Hydrograph: A graph showing flow (discharge) values against time at a given point, usually measured in cubic feet per second (cfs). The area under the curve indicates total volume of flow.

Hydrology (Hydrologic): The branch of science dealing with water, its properties, laws and distribution; the study of rainfall/runoff relationships.

Index Location: A location within a damage reach where stage/damage functions are aggregated and adjusted to account for the slope of water surface profiles throughout

the damage reach. Flood damages are computed and reported at the index location.

One Hundred (100) Year Flood: A flood having a 1 percent chance of being equalled or exceeded in any year. In the past, this flood has also been referred to as the Intermediate Regional Flood.

Orthophosphate: Phosphates may occur in surface or ground water as a result of agricultural runoff, runoff from fertilized lawns and industrial wastes, and as a major element of sewage treatment resulting from the use of detergents containing phosphorus. In surface waters, phosphates are seldom found in significant concentrations because they are used in the growth of aquatic plants. In conjunction with high nitrogen levels, high phosphate concentrations can stimulate the growth of nuisance algal blooms or excessive plant growth in surface water bodies.

Orthophoto: A special map based on aerial photography on which the horizontal distance between points or objects can be measured.

Regulatory Floodway: The channel of a stream plus any adjacent flood plain areas that must be kept free of encroachment in order that the 100-year flood can be carried without substantial increases in flood heights. (A maximum 1 foot rise is permitted under the National Flood Insurance Program).

Runoff: Precipitation that does not evaporate nor enter the ground water system but flows overland until a stream channel is reached.

Spatial Analysis: In this study, a computerized data management and analysis tool designed specifically to handle (mapped) data which relates to a certain size area.

Total Nitrogen: Is a measure of all forms of nitrogen that could be expected in domestic, commercial and industrial sewage treatment effluent waters and stormwater runoff. The nitrogen forms analyzed include organic nitrogen (nitrogen contained in amino acid and proteins of living organisms) and three inorganic forms, ammonia (NH_3), nitrite (NO_2), and nitrate (NO_3). All of these nitrogen forms are commonly found in surface waters and are necessary for the growth of algae, phytoplankton and rooted aquatic plants.

Watershed: The entire land area that is drained by a stream or river system.

Water Surface Profile: A graph showing the relationship of water surface elevation to location, the latter generally expressed as distance above the mouth of a stream. It is generally drawn to show the water surface elevation for the crest of a specific flood, but may be prepared for conditions at a given time or stage.

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